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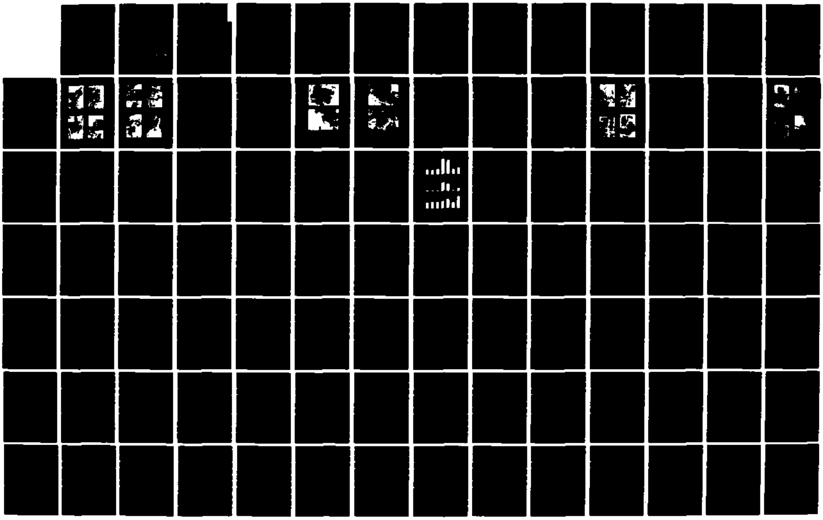

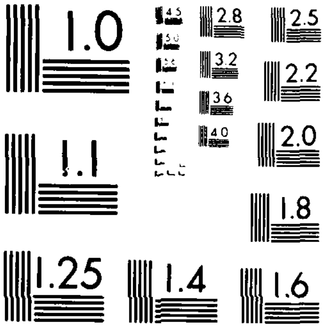

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CLEAN-BURNING DIESEL ENGINES – PHASE II

INTERIM REPORT
AFLRL No. 178

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Prepared for
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Southwest Research Institute
San Antonio, Texas

Under Contract to
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December 1984

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Gaseous, particulate and unregulated emissions were measured from four diesel forklift engines under a variety of steady-state conditions. An EPA certification fuel was used to determine emission rates for CO, CO_2, NO_x, HC, particulate, sulfur dioxide, sulfate, organic sulfides, phenols, DOAS odor and aldehydes. Four engines included in this evaluation were Deutz F3L 912W, Deutz F4L 912W, Perkins 4.2032 and Perkins 4.2482. Additional emission tests were conducted with the Deutz F3L 912W with MIL-F-46162A(MR) and MIL-F-46162B(ME) reference fuels. The Perkins 4.2032 was also evaluated with the MIL-F-46162B(ME) reference fuel. Data from Phase I is also included for comparison purposes.

The effect of selected induced faults on emission rates of the Deutz F3L 912W was also determined. These induced faults included intake air restriction, exhaust restriction and injection pump timing. Emission rates were reported in g/hr, g/hp-hr and concentration, i.e., ppm, percent, $\mu g/m^3$.

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FOREWORD

Work Directive 18, "Clean-Burning Diesel Engines," was issued on September 13, 1982 under Contract DAAK70-82-C-0001 to the U.S. Army Mobility Equipment Research and Development Command (MERADCOM; currently the Belvoir Research and Development Center). This work was expanded to include additional engines and fuels by a contract modification on July 5, 1983. The engineering and analytical efforts of this program were conducted by the Department of Emissions Research of Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78284. This program was identified within Southwest Research Institute as Project 02-6800-175.

This project was under the overall supervision of Harry E. Dietzmann, manager of the Chemical Analysis Section. He was assisted by Dr. Lawrence R. Smith (chemical analysis) and Mr. Orville J. Davis (engine gaseous and particulate emissions). Emission testing was initiated in January 1983 and was completed in March 1984. Mr. Tim Lee of Belvoir Research and Development Center, STRBE-GMW was the project technical officer, Mr. James Stephens and Mr. Irv Rosen served as the overall program managers, Mr. M.E. LePera, Belvoir Research and Development Center, STRBE-VF, served as project coordinator, and Mr. F.W. Schaekel, STRBE-VF was Contracting Officer's Representative.

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I. INTRODUCTION

The United States Army is investigating the possibility of replacing the currently used electric forklift with diesel engine-powered forklifts in handling hazardous materials. Electric-powered forklifts have no noise or air pollution problems, however, the logistic problems associated with field operations have prompted the U.S. Army to investigate other possible alternatives. The most promising candidate is the diesel-powered forklift. Although the diesel engine has many advantages, i.e., mobility, cost, maintenance, the use of diesels in areas of limited ventilation is of concern. This program addresses engine-out emissions from several candidate diesel forklift engines under a variety of conditions.

The use of diesel forklift engines in areas with only limited ventilation is of concern; however, these concerns may be amplified when the vehicle is operating under a malfunction mode. Malfunctions include simulating a plugged air cleaner (inlet air restriction), injection pump timing not property adjusted, and damaged exhaust system (exhaust restriction). The magnitude of these malfunctions was determined on a Deutz F3L 912W. A review of available data on Bureau of Mines Contract No. H0292009 is included to confirm emission trends as well as to look at synergistic effects.

A. <u>Objective</u>

The objective of this program was to expand the exhaust emissions characterization data base of diesel engines considered as potential candidates for forklift vehicles used to handle hazardous materials. A previous emissions characterization program was conducted for gaseous, particulate, and unregulated on a Deutz F3L 912W and a Perkins 4.2032 operating on a MIL-F-46162A(MR) fuel[(1)*]. This program included additional tests on the Deutz F3L

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*Numbers in parentheses designate references at the end of the report.

912W with a MIL-F-46162B(ME) fuel. The MIL-F-46162B(ME) is a high-sulfur reference fuel, and it was of importance to know the relationship of gaseous, particulate, and unregulated emissions (especially sulfur-containing compounds) to the sulfur content of the fuel. The emissions data base was also expanded to include two additional engine models.

B. Scope

Four diesel forklift engines were provided by Belvoir R&D Center for this study, a Deutz F3L 912W, a Deutz F4L 912W, a Perkins 4.2032, and a Perkins 4.2482. Two fuels were required for this program, a MIL-F-46162B(ME) reference fuel and a EPA certification fuel. The MIL-F-46162B(ME) fuel was provided by the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) at Southwest Research Institute. The EPA certification fuel was obtained from Phillips Petroleum Company. Emissions characterization was accomplished over the test matrix in Table 1. Emission rates are presented in g/hp-hr, g/hr, and observed concentrations.

TABLE 1. ENGINES, FUELS AND EMISSIONS TEST MATRIX

Engine	Fuel Code	Emission Measurement Modes			
		Group I	Group II	Group III	Group IV
Deutz F3L 912W	AL-7225-F[a]	26	14	10	--
Deutz F3L 912W	AL-12287-F	13	6	3	3[b]
Deutz F3L 912W	EM-565-F	13	6	3	--
Perkins 4.2032	AL-7225-F[a]	26	14	10	--
Perkins 4.2032	EM-565-F	13	6	3	3
Deutz F4L 912W	EM-565-F	13	6	3	3
Perkins 4.2482	EM-565-F	13	6	3	--

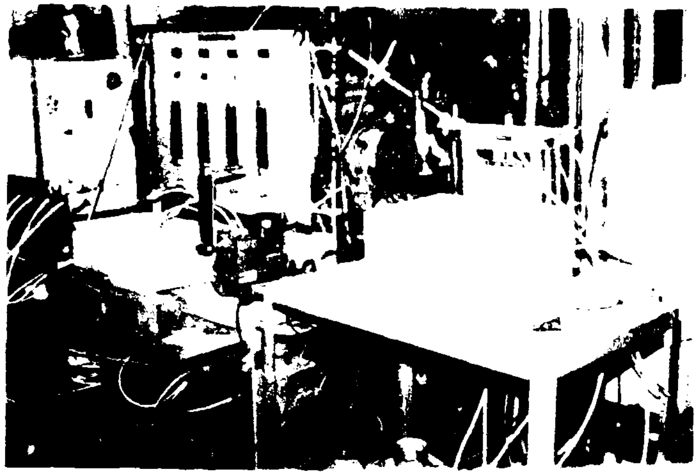
Group I includes CO, CO_2, HC, smoke

Group II includes particulate, SO_2 and sulfate

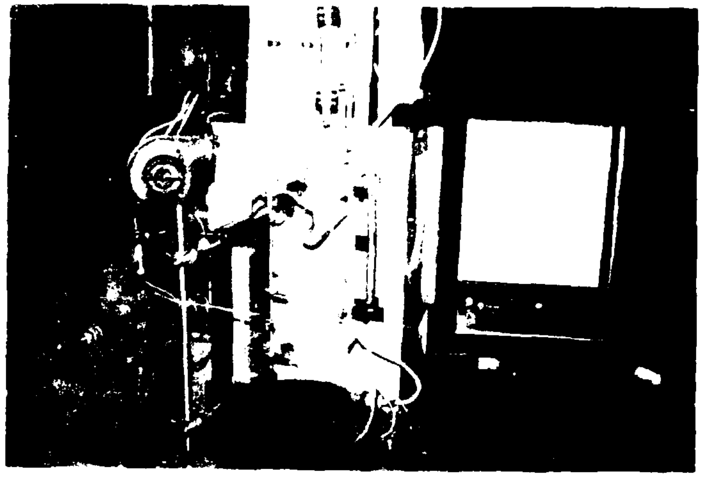
Group III includes aldehydes, organic sulfides, DOAS odor, phenols

Group IV includes GC-MS for priority pollutants

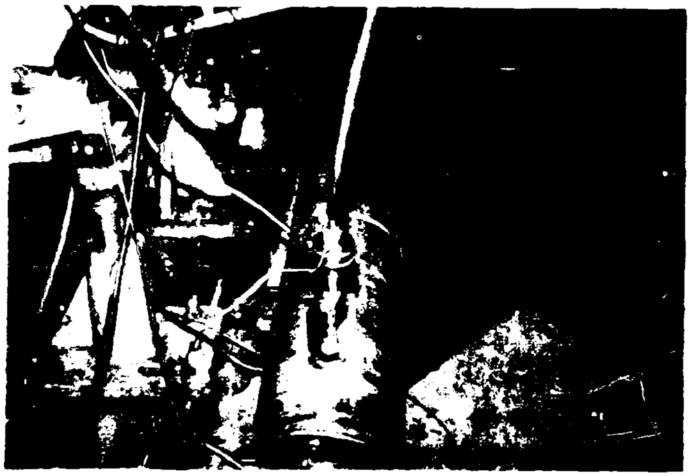
[a]Includes data reported in Interim Report AFLRL No. 169 "Clean Burning Diesel Engines" (AD A145515) to Contract DAAK70-82-C-0001, August 1984.
[b]Selected additional unregulated emissions were measured on four modes, including hydrogen sulfide, hydrogen cyanide, individual hydrocarbons, and nitropyrenes.



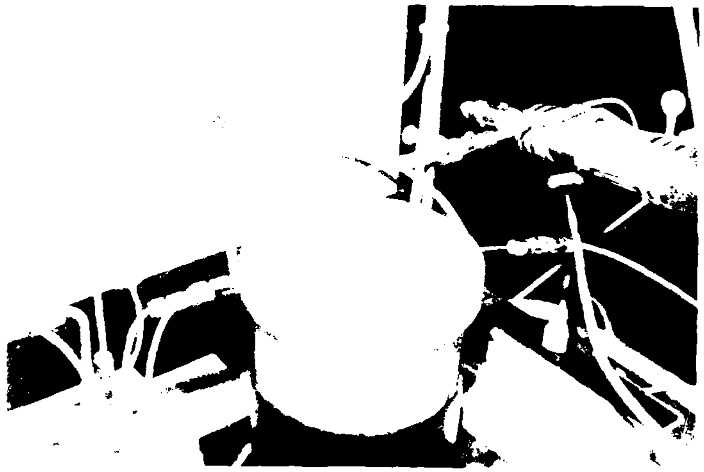
Aldehydes and Phenols



DOAS Odor



Particulate/Sulfate



Organic Sulfides

FIGURE 7. SEVERAL VIEWS OF GROUP II AND III SAMPLING SYSTEMS
(USED WITH DEUTZ F3L 912W AND PERKINS 4.203.2)

III. ANALYTICAL PROCEDURES FOR UNREGULATED EMISSIONS

The analytical procedures used to measure the unregulated emissions are summarized in this section. Detailed descriptions of most of the procedures, along with discussions of their development, validation, and qualification, are available in Interim Report II, "Analytical Procedures for Characterizing Unregulated Pollutant Emissions From Motor Vehicles," developed in a related EPA project.[3] Several views of Group II and III sampling systems are shown in Figure 7.

A. Description of Analytical Procedures

The unregulated emissions evaluated in this project, along with the methods for sampling and the procedures used in the analyses, are listed in Table 7. Aldehydes and ketones, organic sulfides, and phenols represent groups of compounds. The respective procedures separate and identify a number of individual components within each of these groups. The analytical procedures involved in this project are briefly described in the following subsections.

1. Aldehydes and Ketones

The collection of aldehydes (formaldehyde, acetaldehyde, acrolein, propionaldehyde, crotonaldehyde, isobutyraldehyde, benzaldehyde, and hexanaldehyde) and ketones (acetone and methylethylketone) is accomplished by bubbling exhaust through glass impingers containing 2,4 dinitrophenylhydrazine (DNPH) in dilute hydrochloric acid. The aldehydes and ketones (also known as carbonyl compounds) react with the DNPH to form their respective phenylhydrazone derivatives. These derivatives are insoluble or only slightly soluble in the DNPH/HCl solution and are removed by filtration followed by pentane extractions. The filtered precipitate and the pentane extracts are combined, and then the pentane is evaporated in a vacuum oven. The remaining dried extract contains the phenylhydrazone derivatives. The extract is dissolved in a quantitative volume of methanol, and a portion of this dissolved

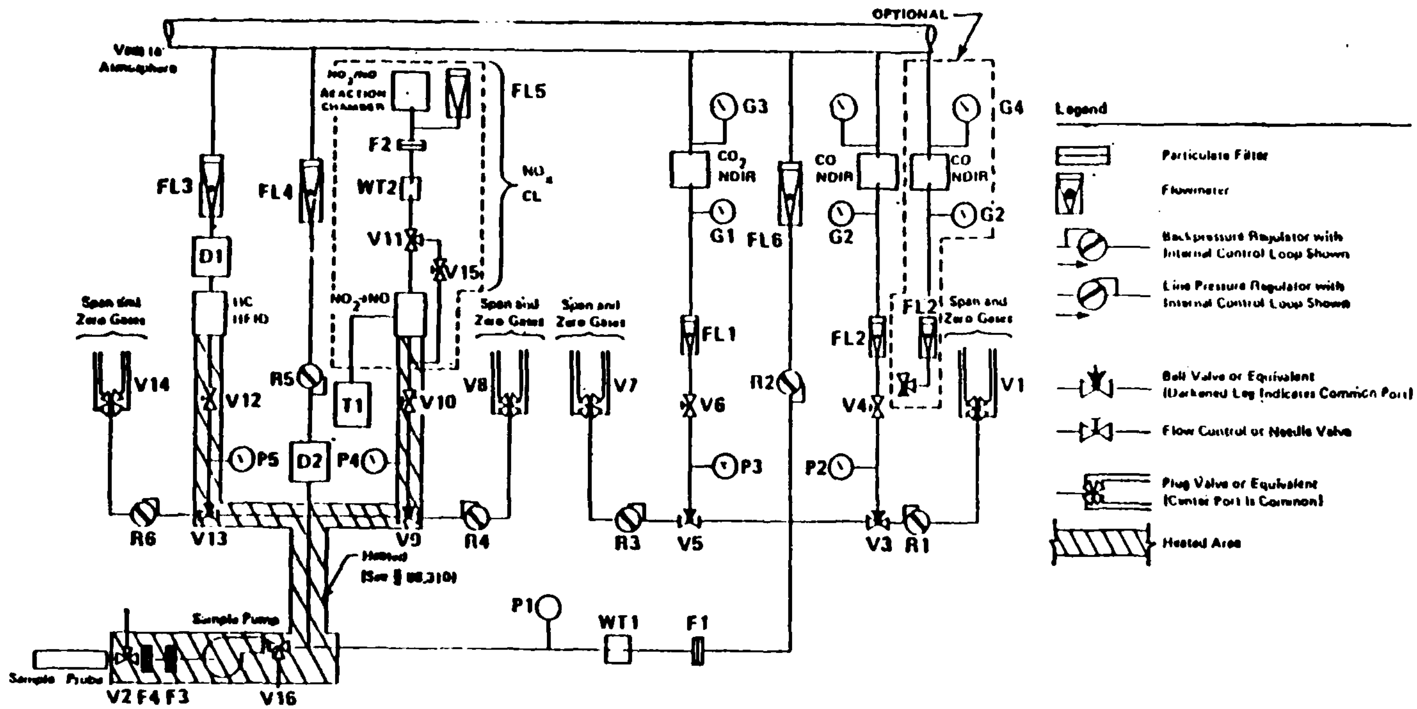
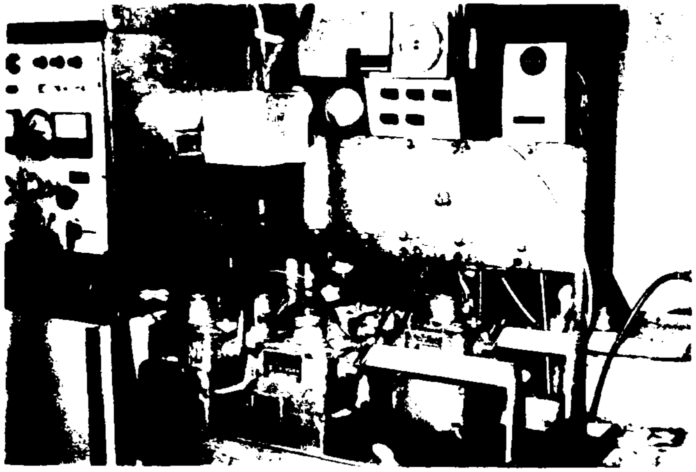
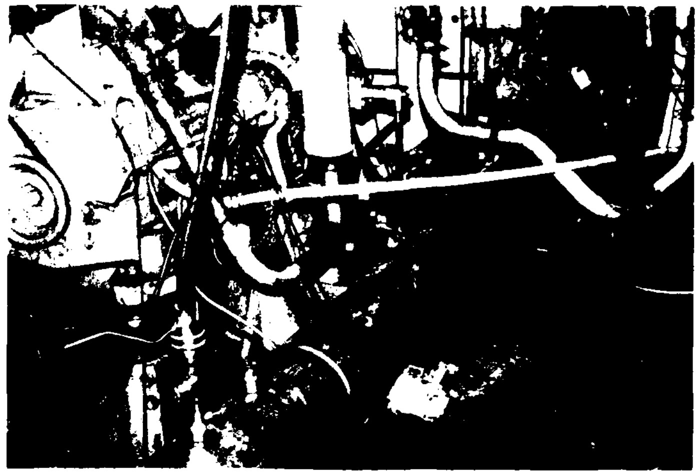


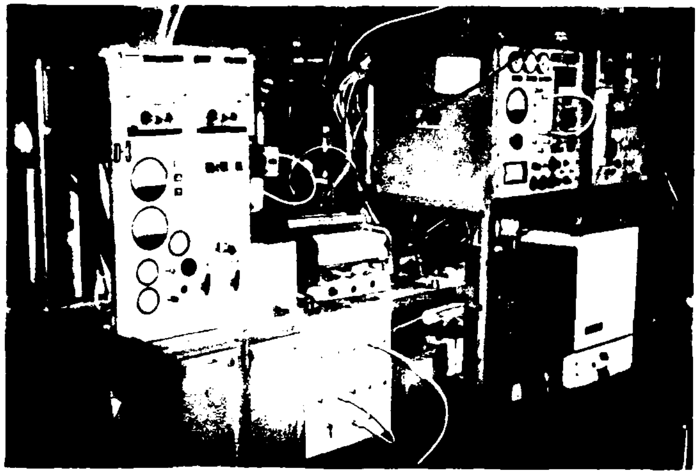
FIGURE 6. GASEOUS EMISSIONS CART FLOW SCHEMATIC



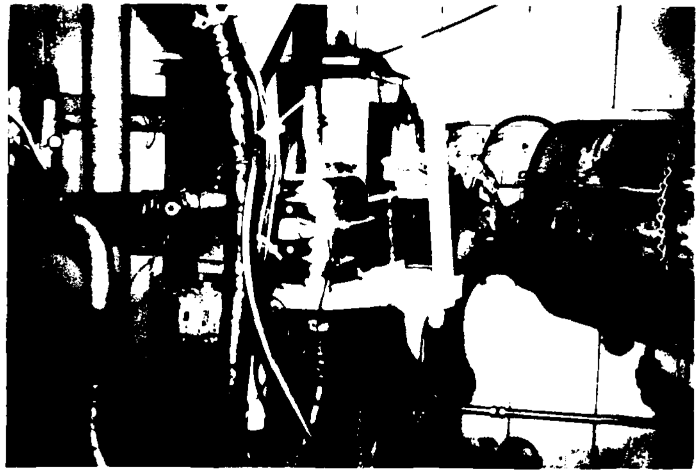
Particulate Sampling Controls



Dilution Tunnel



Gaseous Emissions Cart



Heated Interface

FIGURE 3. SEVERAL VIEWS OF GASEOUS AND PARTICULATE EMISSIONS INSTRUMENTATION

D. Gaseous Emissions (Group I)

The measurement of gaseous emissions was accomplished using analytical equipment, procedures, and calculations specified in the Federal Register[2] for 13-mode certification testing. The specific analytical instruments used in this study are listed in Table 6, and several views of this equipment are also illustrated in Figure 5. A flow schematic of the gaseous emissions instrumentation is shown in Figure 6. One set of gaseous, particulate, and unregulated emissions instrumentation was used to obtain emissions data on this program. The proximity of the two test stands and the common exhaust system allowed ready changing between test stands.

TABLE 6. LIST OF GROUP I EMISSION MEASUREMENT EQUIPMENT

Exhaust Species	Chemical Symbol	Detection Technique	Instrument
Carbon Monoxide	CO	NDIR[a]	Beckman 315B
Carbon Dioxide	CO_2	NDIR[a]	Beckman 315B
Oxides of Nitrogen	NO_x	CL[b]	SwRI w/EPA Design
Hydrocarbons	HC	FID[c]	SwRI w/Beckman 402 Detector
Smoke	--	Opacity	PHS Smokemeter

[a]NDIR denotes nondispersive infrared
[b]CL denotes chemiluminescent analyzer
[c]FID denotes flame ionization detector

TABLE 5. TEST FUEL INSPECTION DATA

Fuel Property	MIL-F-46162A(MR) Fuel Specification	MIL-F-46162A(MR) AL-7225-F Analysis	MIL-F-46162B(ME) Fuel Specification	MIL-F-46162B(ME) AL-12287-F Analysis	EPA DF-2 Certification Fuel Specification	EPA DF-2 Certification EM-565-F Analysis
Gravity, °API	33-37	36.1	NA	32.9	33-37	33.1
Density, g/mL	0.84-0.85	0.844	Report	0.8603	NA	NA
Flash Point, °C	>56	60	Report	70	>49	66
Cloud Point, °C	<-13	-21	≤-13	-18	NA	NA
Pour Point, °C	<-18	-24	≤-18	-20	NA	NA
Viscosity, cSt, @ 40°C	2.2-3.2*	2.2	1.9-4.1	2.66	2.0-3.2*	3.0
Distillation, °C						
IBP	171-204	166	Report	193	171-204	198
10% Recovered	204-238	219	Report	228	204-238	239
50% Recovered	243-282	244	245-285	264	243-282	273
90% Recovered	288-321	296	330-387	319	288-321	312
EBP	304-349	358	≤385 max	357	304-349	338
Carbon Residue (10% Bottom)	<0.20	0.15	≤0.20 max	0.16	NA	NA
Ash, wt % max	<0.02	0.01	0.02	0	NA	NA
Cu Strip Corrosion	Report	1A	1 max	1A	NA	NA
Acceleration Stability, mg/100 mL	1.0 max	0.60	1.5 max	1.83	NA	NA
Neutral Number	≤0.01	0.01	<0.2	0.04	NA	NA
Aromatics, vol %	≥27.0	27.5	Report	37.9	>27.0 min	39.8
Sulfur, %	0.35-0.70	0.35	0.95-1.05	1.03	0.2-0.5	0.4
Cetane Number	>42	48	40-45	53	42-50	47.1
Particulate, mg/L			10 max	10	NA	NA

*Viscosity at 37.8°C (100°F)

TABLE 4. ENGINE PERFORMANCE DATA AFTER 80-HOUR BREAK-IN ON DEUTZ F4L 912W AND PERKINS 4.2482 ENGINES

Deutz F4L 912W			Perkins 4.2482		
Engine RPM	Horsepower, hp	BSFC, lb/hp-hr	Engine RPM	Horsepower, hp	BSFC, lb/hp-hr
2300	57.3	0.457	2300	74.0	0.375
2100	55.1	0.445	2100	72.9	0.369
1900	52.5	0.431	1900	68.2	0.363
1700	48.1	0.434	1700	63.0	0.361
1500	42.8	0.415	1500	56.8	0.364
1300	36.2	0.415	1300	49.2	0.374
1100	30.7	0.407	1100	39.4	0.384
900	17.2	0.417	900	30.1	0.399

B. Fuel Description

This program provided for emission testing using two DF-2 reference fuels. The first fuel was designed to meet MIL-F-46162B(ME) specifications and was provided by the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) at Southwest Research Institute. The second fuel, a DF-2 fuel, met EPA certification specifications and was obtained from Phillips Petroleum Company. The fuel inspection data on the two test fuels are presented in Table 5.

C. Dynamometer Description

A 250-hp Midwest wet-gap, eddy-current dynamometer was used to determine the load on the Deutz F3L 912W, and an adjacent 175-hp Midwest dry gap eddy current dynamometer measured the engine load on the Perkins 4.2032, Perkins 4.2482, and Deutz F4L 912W engines. A 0-30 lb/hr Flotron was used to determine fuel consumption. An 8-inch stainless steel dilution tunnel was used to collect particulate samples. All equipment was calibrated prior to testing using accepted applicable procedures, i.e., Federal Register, SAE, EPA Recommended Practice, etc.

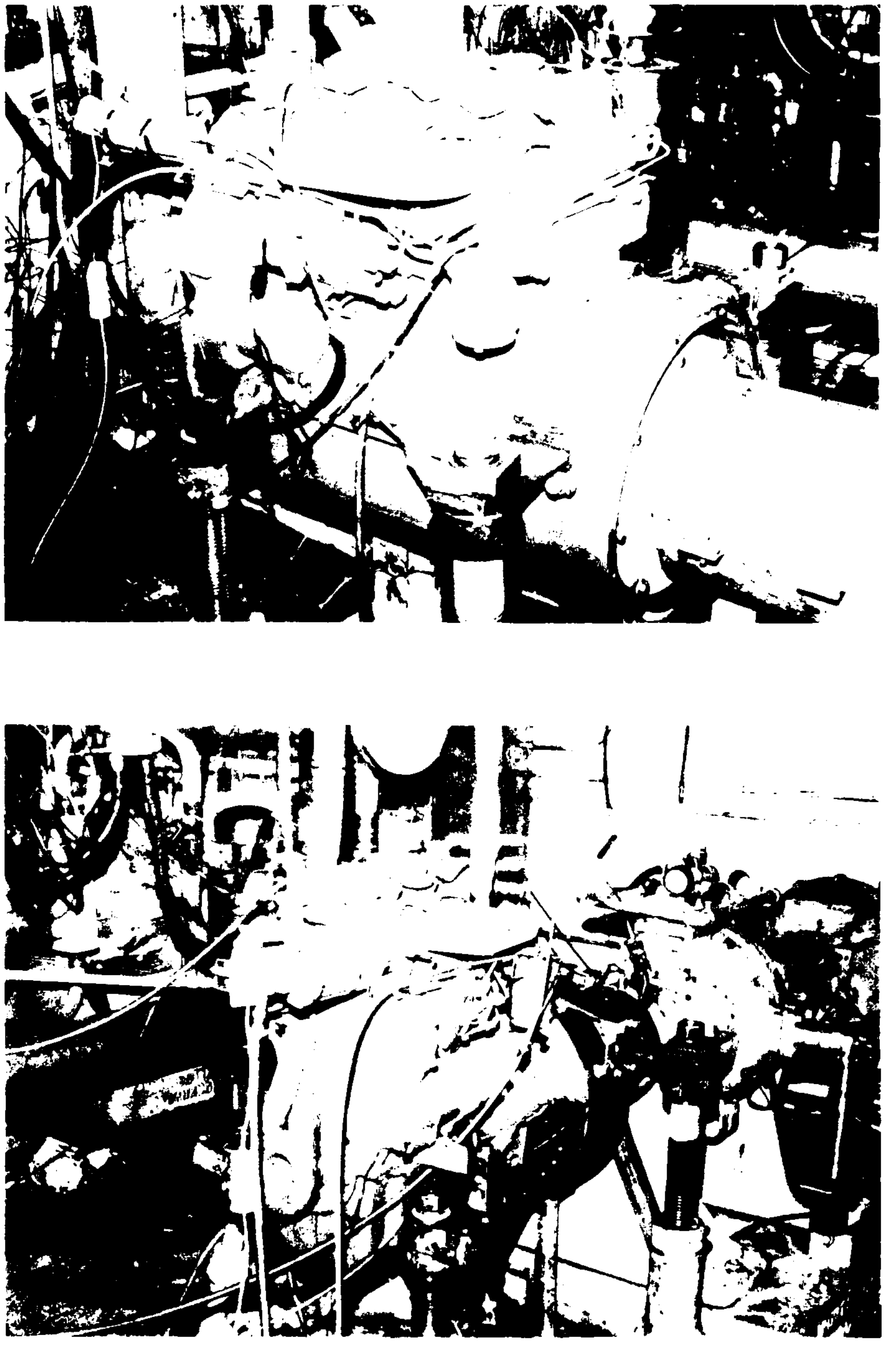


FIGURE 4. SEVERAL VIEWS OF PERKINS 4.2482 ON THE TEST STAND

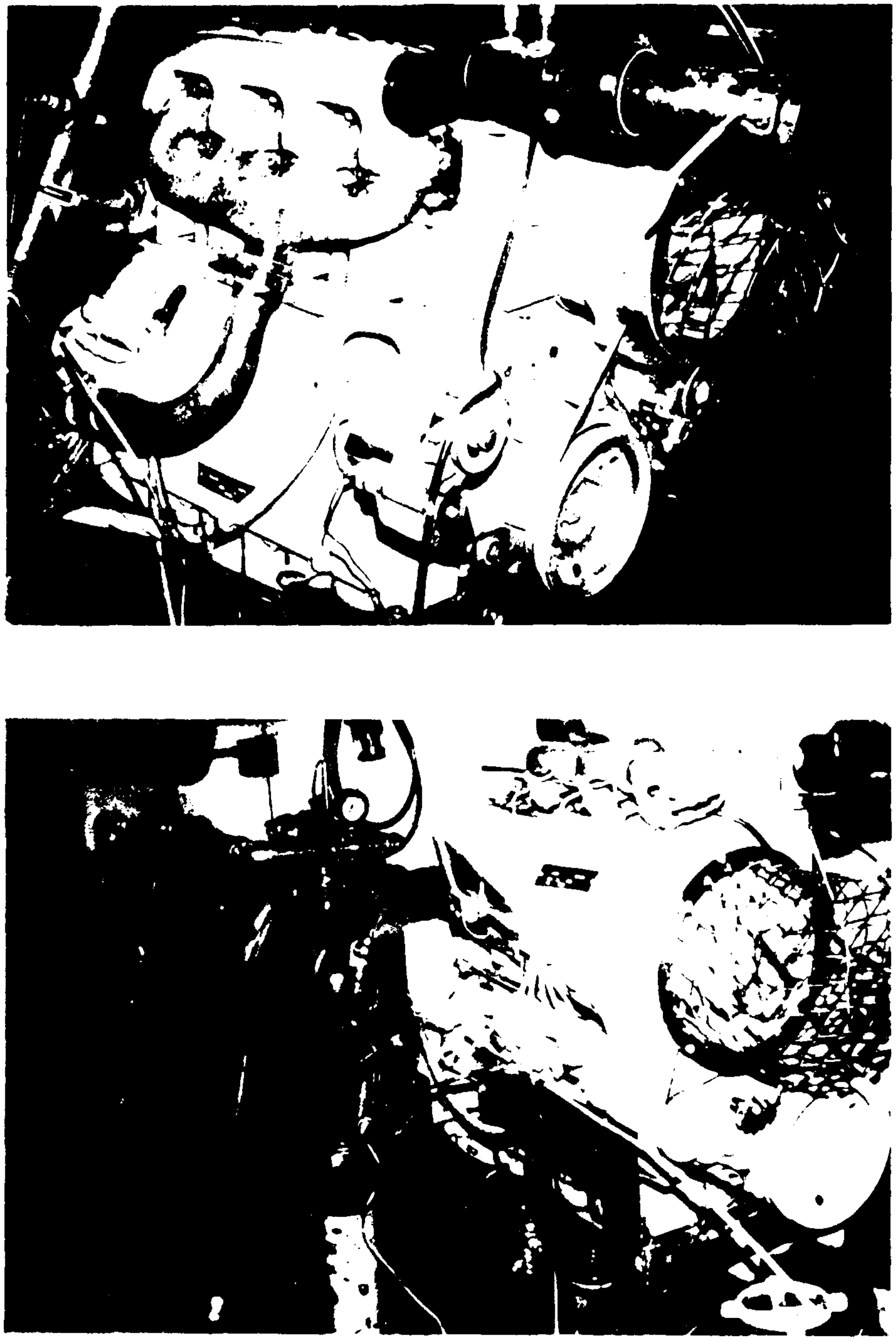


FIGURE 3. SEVERAL VIEWS OF DEUTZ F4L 912W ON THE TEST STAND

TABLE 3. BREAK-IN SCHEDULE FOR DEUTZ F4L 912W AND PERKINS 4.2482

Step No.	Time per Step	Total Time	RPM	Beam Load, lb	Remarks
1	0:30	0:30	800	20	
2	0:30	1:00	1200	30	
3	1:00	2:00	1400	30	
4	1:00	3:00	1600	35	
5	1:00	4:00	1800	55	
6	1:00	5:00	2000	55	
7	7 hours cycling	0:05	800	20	7 cycles
	(Total Time-	0:25	1200	30	
	12:00 hr)	0:05	800	20	
		0:25	1600	35	
8	8 hours cycling	0:05	1200	30	8 cycles
	(Total Time-	0:25	1800	55	
	20:00 hr)	0:05	1200	30	
		0:25	2200	55	
9	10 hours cycling	0:15	1200	30	10 cycles
	(Total Time-	0:15	1600	35	
	30:00 hr)	0:15	1400	30	
		0:15	1800	55	
10	10 hours cycling	0:15	1600	35	10 cycles
	(Total Time-	0:15	2200	55	
	40:00 hr)	0:15	2000	55	
		0:15	2300	60	

Repeat entire sequence to give a total of 80 hours

TABLE 2. ENGINE PERFORMANCE DATA ON DEUTZ F3L 912W AND PERKINS 4.2032 DETERMINED 12 July 1983

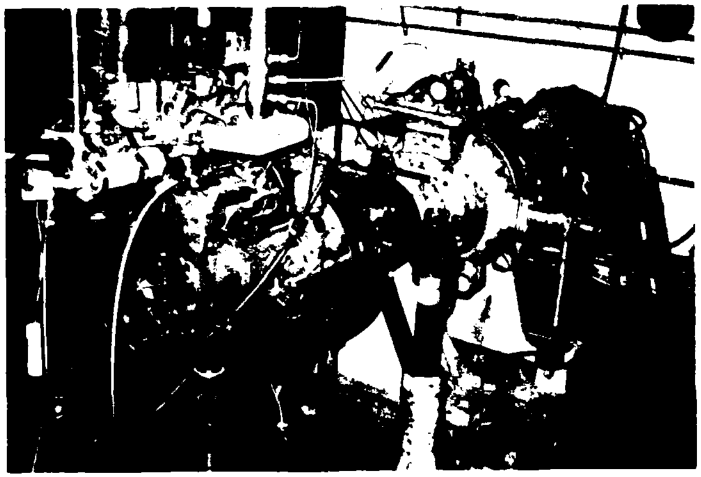
Deutz F3L 912W			Perkins 4.2032		
Engine RPM	Horsepower, hp	BSFC lb/hp-hr	Engine RPM	Horsepower, hp	BSFC lb/hp-hr
2650	43.7	0.472	2500	52.5	0.430
2400	45.0	0.437	2300	49.7	0.402
2200	42.8	0.420	2100	47.1	0.394
2000	39.2	0.420	1900	44.0	0.384
1800	36.5	0.433	1700	40.9	0.384
1600	34.3	0.421	1500	37.4	0.385
1400	29.5	0.420	1300	32.9	0.381
1200	25.0	0.428	1100	27.3	0.374
1000	20.2	0.435	900	21.6	0.397
800	15.4	0.435	700	15.8	0.401
600	10.2	0.464	500	9.6	0.396

3. Deutz F4L 912W Engine Description

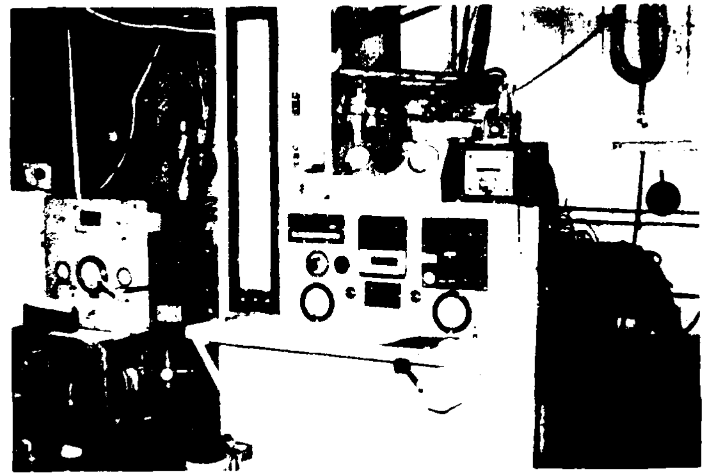
The Deutz F4L 912W engine was supplied new by Belvoir R&D Center. This engine was a four-cylinder, air-cooled diesel engine rated at 59 hp at 2300 rpm. The engine was run using the inlet and outlet exhaust restrictions provided by Deutz. The new engine underwent an 80-hour engine break-in using the break-in schedule presented in Table 3. Engine performance data are presented in Table 4. The engine was received in satisfactory operating condition and underwent the 80-hour break-in and emission test program without incident. Several views of the Deutz F4L 912W on the test stand are illustrated in Figure 3.

4. Perkins 4.2482 Engine Description

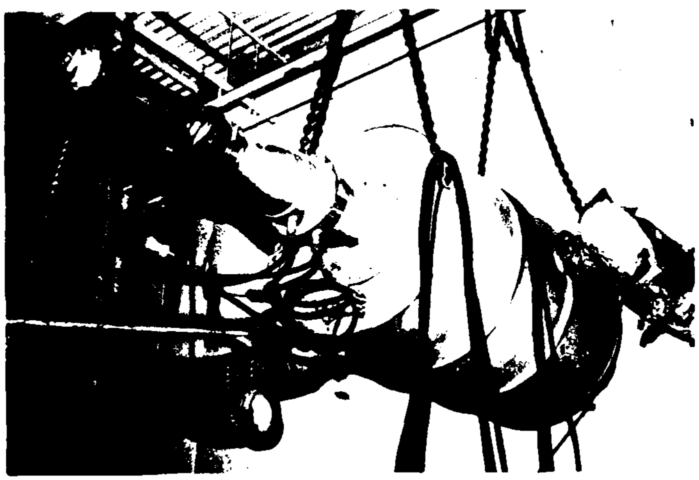
A new four-cylinder, water-cooled Perkins 4.2482 diesel engine was supplied by Belvoir R&D Center for this program. This engine was rated at 80 hp at 2300 rpm and underwent the break-in schedule presented in Table 3 prior to emissions testing. The engine performance data for the Perkins 4.2482 are illustrated in Table 4. Figure 4 illustrates the Perkins 4.2482 engine on the test stand.



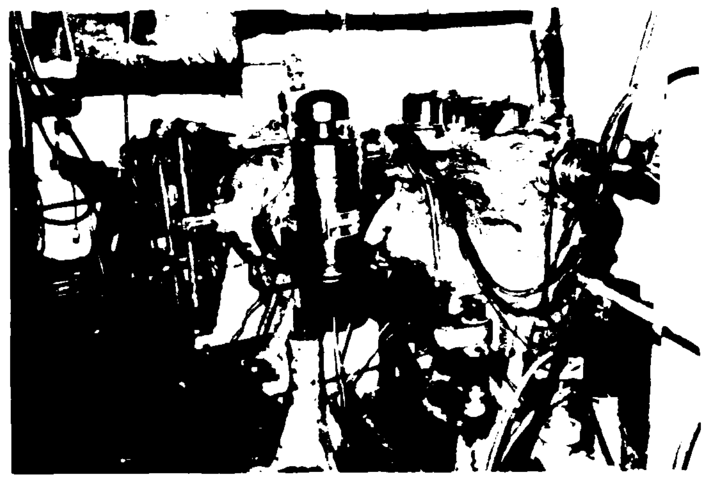
Port View of Perkins 4.203.2



Control Console

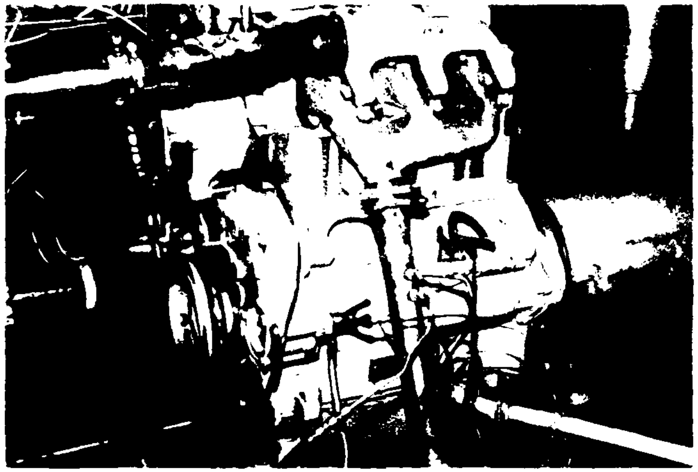


Intake Air Measurement System

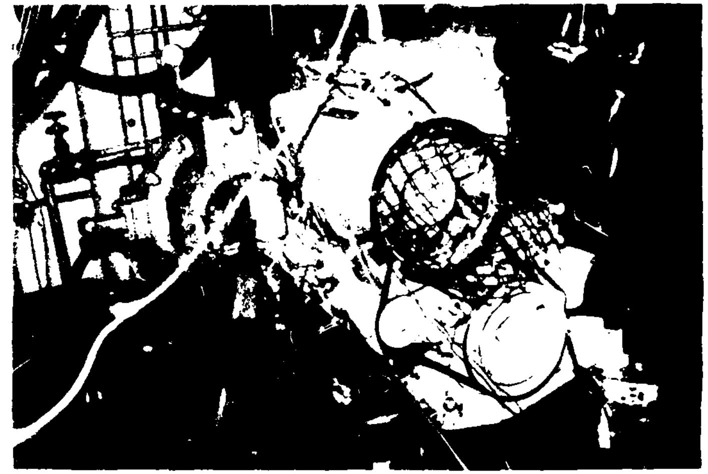


Starboard View of Perkins 4.203.2

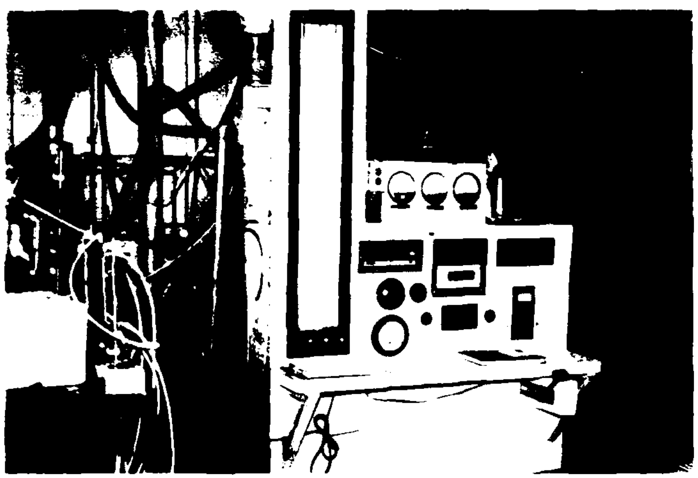
FIGURE 2. SEVERAL VIEWS OF THE PERKINS 4.203.2 ON THE TEST STAND



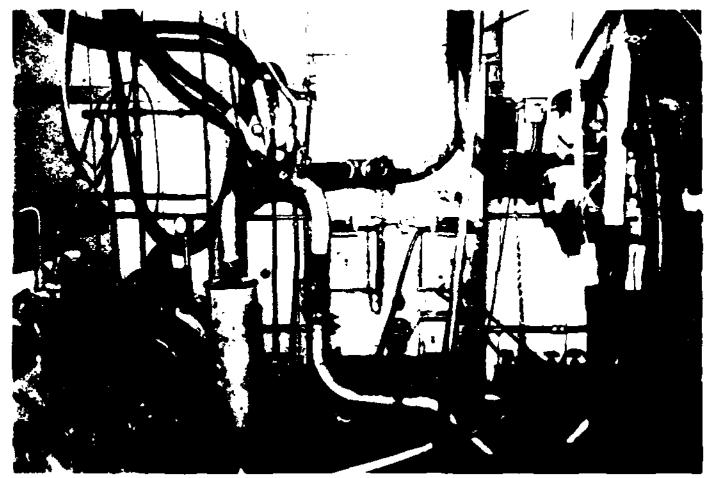
Port View of Deutz F3L 912W



Starboard View Deutz F3L 913



Control Console



Exhaust System

FIGURE 1. SEVERAL VIEWS OF THE DEUTZ F3L 912W ON THE TEST STAND

II. DESCRIPTION OF FACILITIES, ENGINES, AND PROCEDURES

A. Engine Description

This program involved emission mapping for gaseous, particulate, and unregulated emissions from a Deutz F3L 912W engine operating on a high-sulfur reference fuel, MIL-F-46162(B)ME (AL-12287-F). Four candidate diesel forklift engines were tested using an EPA certification DF-2 reference fuel. These engines included two Deutz engines (F3L 912W and F4L 912W) and two Perkins diesel engines (4.2032 and 4.2482). All engines were supplied by Belvoir R&D Center.

1. Deutz F3L 912W Engine Description

The first engine tested in this program was a Deutz F3L 912W engine rated at 48 hp at 2650 rpm. This engine was supplied to SwRI by Belvoir R&D Center on an earlier program, and no engine break-in was required. Several views of the Deutz F3L 912W on the test stand are illustrated in Figure 1. The engine performance data for the Deutz F3L 912W prior to the start of this program are presented in Table 2.

2. Perkins 4.2032 Engine Description

A Perkins 4.2032 four-cylinder, water-cooled diesel engine was tested in this program. This engine was rated at 59 hp at 2500 rpm and was used on an earlier program for Belvoir R&D Center. The engine had previously undergone the 80-hour break-in, and only a performance map was accomplished prior to emission testing on this program. The engine performance data are presented in Table 2, and several views of the Perkins 4.2032 on the test stand are illustrated in Figure 2.

extract is injected into a liquid chromatograph and analyzed for several individual aldehydes and ketones using an ultraviolet detector.

TABLE 7. SAMPLING AND ANALYSIS METHODOLOGY FOR UNREGULATED EMISSIONS

Compound	Sampling	Method of Analysis
Aldehydes and Ketones	Impinger	Dinitrophenylhydrazone derivative. Liquid chromatograph with ultraviolet detector (LC-UV).
Sulfur Dioxide	Impinger	Ion chromatograph
Carbonyl Sulfide (COS) and Organic Sulfides	Trap	Gas chromatograph with flame photometric detector (GC-FPD)
Sulfate	47-mm filter	Barium chloranilate derivative (BCA). Liquid chromatograph with ultraviolet detector (LC-UV)
Particulates	47-mm filter	Weighed using microbalance
Phenols	Impinger	Gas chromatograph with flame ionization detector (GC-FID)
DOAS	Trap	Liquid chromatograph with ultraviolet detector (LC-UV)
GC-MS General	20x20 filter	Gas chromatograph-Mass Spectral Analysis (GC-MS)

2. Sulfur Dioxide

The concentration of sulfur dioxide in exhaust is determined as sulfate using an ion chromatograph. Sulfur dioxide is collected and converted to sulfate by bubbling dilute exhaust through two glass impingers containing 3-percent hydrogen peroxide absorbing solution. The samples are analyzed on the ion chromatograph and compared to standards of known sulfate concentrations.

3. Carbonyl Sulfide and Organic Sulfides

The collection of carbonyl sulfide (COS) and the organic sulfides, methyl sulfide (dimethylsulfide $(CH_3)_2S$), ethyl sulfide (diethylsulfide $(C_2H_5)_2S$), and methyl disulfide (dimethyl disulfide $(CH_3)_2S_2$), is accomplished by passing exhaust through Tenax GC traps at -76°C. At this temperature, the traps remove the organic sulfides from the exhaust. The organic sulfides are thermally desorbed from the traps into a gas chromatograph sampling system and injected into a gas chromatograph equipped with a flame photometric detector for analysis. External organic sulfide standards generated from permeation tubes are used to quantify the results.

4. Sulfate

The exhaust is vented into a dilution tunnel where it is mixed with a stream of filtered room air. In the tunnel, the SO_3 reacts rapidly with water in the exhaust to form sulfuric acid aerosols. The aerosols grow to a filterable size range within the tunnel and are collected on a fluorocarbon membrane filter. Particulate sulfate salts are also collected on the filter.

Sulfuric acid collected on the filter is then converted to ammonium sulfate by exposure to ammonia vapor. The soluble sulfates are leached from a filter with a measured volume of an isopropyl alcohol-water solution (60 percent IPA). A fixed volume of the sample extract is injected into a high-pressure liquid chromatograph (HPLC) and pumped through a column of strong cation exchange resin in Ag^+ form to scrub out the halides (Cl^-, Br^-) and then through a column of strong cation exchange resin in H^+ form to scrub out the cations and convert the sulfate to sulfuric acid. Passage through a reactor column of barium chloranilate crystals precipitates out barium sulfate and releases the highly UV-absorbing chloranilate ions. The amount of chloranilate ions released is equivalent to the sulfate in the sample and is measured by a sensitive liquid chromatograph UV detector at 310-313 nanometers. All the reactions and measurements take place in a flowing stream of 60 percent IPA. The scrubber and reactor columns also function as efficient filter media for any solid

reaction products formed during passage of the sample through the column system.

5. Particulate

Engine exhaust was diluted with filtered ambient air in an 8-inch (20.3 cm) stainless steel dilution tunnel.[4] Air dilution was varied to maintain temperatures at the filter of less than 125°F (52°C). Particulate was collected on pre-weighed 47-mm Pallflex filters and weight gain determined by re-weighing the filter. Particulate emission rates were expressed in g/hr and g/hp-hr.

6. Phenols

Phenols (phenol; salicylaldehyde; m-cresol/p-cresol; p-ethylphenol/2-isopropylphenol/2,3-xylenol/3,5-xylenol/2,4,6-trimethylphenol; 2,3,5-trimethylphenol; and 2,3,5,6-tetramethylphenol) in exhaust are sampled and quantitatively analyzed with a gas chromatograph (GC) equipped with a flame ionization detector. The exhaust is passed through two Greenburg-Smith impingers in series, each containing 200 mL of 1 N KOH chilled in an ice bath. The contents of each impinger are acidified and extracted with diethyl ether. The samples are partially concentrated, combined, and then further concentrated to about 1 mL. An internal standard is added, and the volume is adjusted to 2 mL. The final sample is analyzed by the use of a GC, and concentrations of individual phenols are determined by comparison to external and internal standards.

7. Diesel Odor Analysis System (DOAS)

The Diesel Odor Analysis System (DOAS) separates and measures the quantity of the odorous components present in a collected diesel exhaust sample eluted from an exhaust sampling trap charged with Chromosorb 102. The separation is achieved by liquid-column chromatography on a silica-type adsorbent, and the detection unit is a UV detector sensitive to 254-nm radiation.

8. Gas Chromatograph-Mass Spectrometer Analysis

Diesel particulate is collected on 20 inch by 20 inch (50.8 cm) Pallflex filters using an 8-inch (20.3 cm) stainless steel dilution tunnel. The organic portion of the diesel particulate is separated from the inorganic particulate matter using a soxhlet extraction with methylene chloride. The methylene chloride solution containing dissolved organics is reduced to dryness (constant weight) using a vacuum rotary evaporator followed by nitrogen blow-down in an inert atmosphere.

A Gas Chromatograph-Mass Spectrometer (GC-MS) analysis of the organic extractables was conducted using a gas chromatograph with a 30-meter fused silica capillary column with a DB-5 liquid phase. The injection temperature was 280°C, with the oven temperature program starting at 40°C for 1 minute, then to 310°C at 10°C/minute. No sample transfer line was used, i.e., capillary was threaded directly into the MS source. The ionization energy of the mass spectrometer was 70 ev and operated over a mass range of 30-525 at 1-second scans.

Selected compounds specifically searched for included the priority pollutant polynuclear aromatic hydrocarbons (PAHs) and other nitroaromatics listed in Table 8. Additional analyses were performed on the aromatic fraction of each extract obtained from silica gel chromatography.

B. Accuracy of the Analytical Procedures

A difficult, but very important, endeavor was the determination of procedural accuracy for each analytical method. The primary difficulty involved those procedures in which the exhaust compounds are trapped or absorbed, an extraction or subsequent reaction is performed, and then a portion of the extraction is analyzed. The decision was reached to initially define the

accuracy in terms of a "minimum detection value" (MDV). The MDV, as used in this report, is defined as the value above which it can be said that the compound has been detected in the exhaust (i.e., at a measured value equal to the MDV, the accuracy is equal to plus or minus the MDV). Determination of accuracy over the entire range of each procedure was beyond the scope of this project.

For compounds collected by bag samples, the MDV was determined from the instrument detection limits only, and is independent of the sampling rate and duration. For compounds which are concentrated in impingers or traps, the MDV is dependent on the instrument detection limit, chemical workup, sampling rate, and sampling duration. The MDV's listed in Table 9 were derived using the listed sampling rate and a 10-minute sampling period.

TABLE 8. GAS CHROMATOGRAPH MASS SPECTROMETER TARGET COMPOUNDS

Priority Pollutant PAHs:	Selected Nitro PAHs:
fluorene	nitronaphthalene
phenanthrene	dinitronaphthalene
anthracene	nitrofluorene
fluoranthene	nitroanthracene
pyrene	nitrodibenzothiophene
benz(a)anthracene	dinitroanthracene
chrysene	nitrofluoranthene
benzo(b)fluoranthene	nitropyrene
benzo(d)fluoranthene	dinitrofluorene
benzo(a)pyrene	
indeno(1,2,3-CD)pyrene	
dibenzo(a,h)anthracene	
benzo(g,h,i)perylene	

TABLE 9. UNREGULATED EMISSION PROCEDURAL SAMPLE RATES AND ACCURACY

	Sample Flow, L/min	Procedural Minimum Detection Values ppm	Procedural Minimum Detection Values $\mu g/m^3$	MDV for 10 min SS Test, mg/hour
Aldehydes and Ketones	4			
Formaldehyde		0.01	15	2
Acetaldehyde		0.01	20	2
Acrolein		0.01	25	3
Propionaldehyde		0.01	25	3
Acetone		0.01	25	3
Crotonaldehyde		0.01	30	3
Isobutyraldehyde		0.01	30	3
Methylethylketone		0.01	30	3
Benzaldehyde		0.01	45	5
Hexanaldehyde		0.01	40	5
Sulfur Dioxide	4	0.05	135	15
Organic Sulfides	0.13			
Carbonyl Sulfide		0.001	3	1
Methyl Sulfide		0.001	3	1
Ethyl Sulfide		0.001	3	1
Methyl Disulfide		0.001	5	1
Sulfate	14	0.01	6	1
Particulate	14	----	50	5
Phenols	14			
Phenol		0.03	125	15
Salicylaldehyde		0.03	150	15
m-/p-cresol		0.02	100	10
Five phenols*		0.02	250	30
2-n-Propylphenol		0.05	75	10
2,3,5-Trimethylphenol		0.01	50	5
2,3,5,6-Tetramethylphenol		0.01	25	5

*Includes sum of p-ethylphenol + 2-isopropylphenol + 2,3-xylenol + 3,5-xylenol + 2,4,6-trimethylphenol

IV. RESULTS

A. Basic Test Matrix

This section presents emission results from four engines operating on one or more fuels. The test matrix for this evaluation is presented in Table 1. Group I emissions (HC, CO, CO_2 and smoke) were measured on each engine fuel combination over the EPA 13-mode cycle, while Group III emissions (particulate, sulfate and sulfur dioxide) were determined on six of the 13 modes. Group II emissions (aldehydes, organic sulfides, phenols and DOAS odor) were obtained on three of the 13 modes. Group IV (GC-MS for EPA priority pollutants) emissions were measured on three of the 13 modes for the Deutz F4L 912W and the Perkins 4.2032. Data from Phase II is also included for comparison purposes.

1. Group I Emissions

Thirteen-mode emission tests are used as the primary basis of comparison for regulated emissions, i.e., CO, NO_x, HC and CO_2. Results of each individual 13-mode emission test are presented in Tables A-1 through A-7 of Appendix A. These results are summarized in Table 10, and a comparison of emission rates is illustrated in Figure 8.

The Deutz F3L 912W was evaluated with three fuels, a MIL-F-46162A(MR) reference fuel (AL-7225-F), a MIL-F-46162B(ME) reference fuel (AL-12287-F) and an EPA certification fuel (EM-565-F). The absolute values of CO and HC emission rates from this engine were quite low, and any changes in emissions due to fuel effects were minimal. Although the NO_x levels were somewhat higher than the CO and HC emissions, the NO_x emission rates were also apparently unaffected by fuel composition. The major difference in the fuel specifications is primarily the amount of allowable sulfur. A summary of the individual modes of the 13-mode tests with each of the three fuels with the

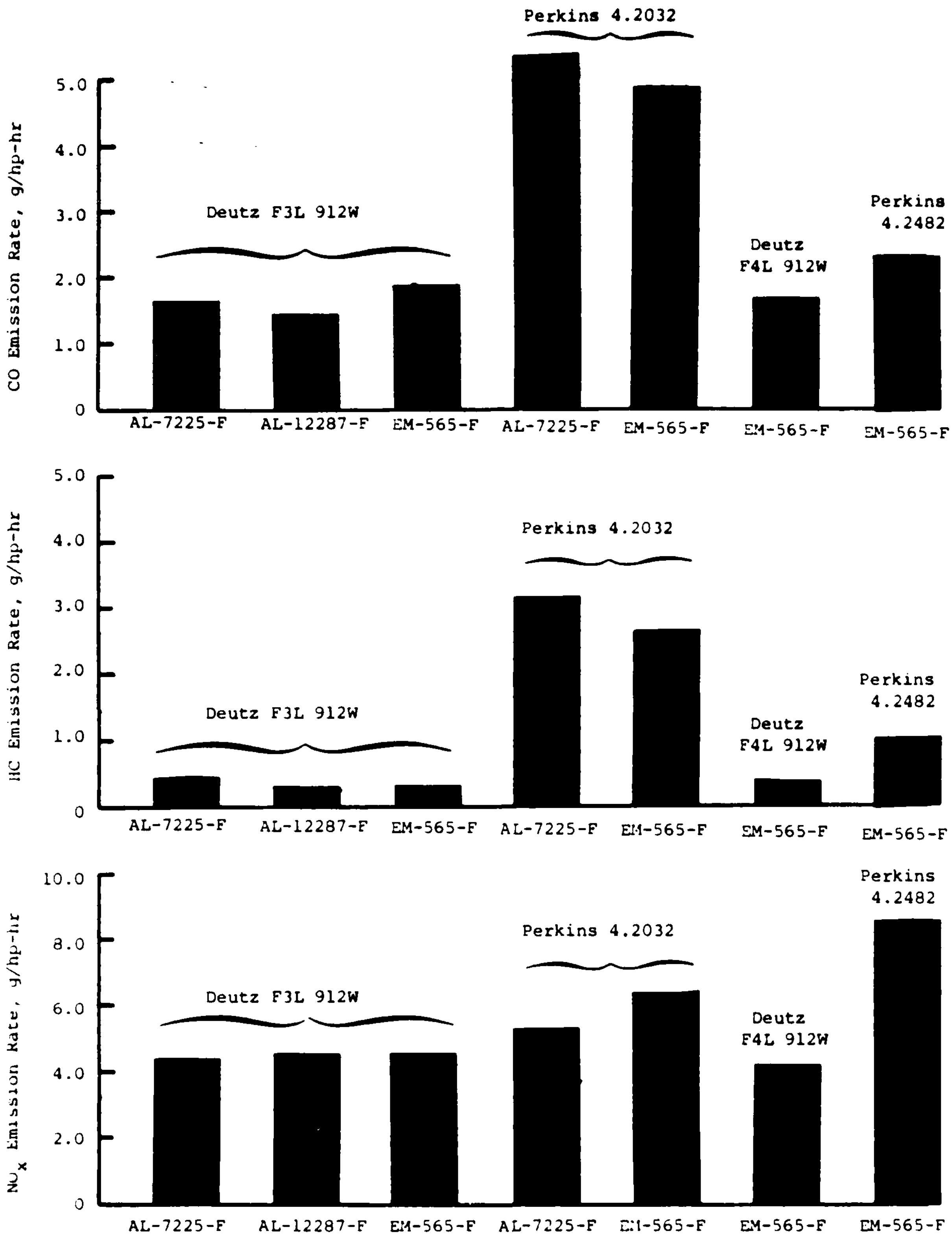


FIGURE 8. COMPARISON OF HC, CO, AND NO_X 13-MODE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES

Deutz F3L 912W is presented in Table 11. This provides an opportunity to compare emission rates (g/hr, g/hp-hr, ppm or percent) and emission concentrations as a function of fuels for each individual mode.

TABLE 10. SUMMARY OF 13-MODE EMISSION RESULTS

Engine Description	Fuel Code	Emission Rate, g/hp-hr CO	HC	NO_x
Deutz F3L 912W	AL-7225-F	1.627	0.454	4.445
Deutz F3L 912W	AL-12287-F	1.472	0.335	4.684
Deutz F3L 912W	EM-565-F	1.851	0.385	4.679
Perkins 4.2032	AL-7225-F	5.438	3.205	5.361
Perkins 4.2032	EM-565-F	4.879	2.740	6.406
Deutz F4L 912W	EM-565-F	1.691	0.409	4.302
Perkins 4.2482	EM-565-F	2.396	1.060	8.647

Thirteen-mode emission tests were conducted on a Perkins 4.2032 with AL-7225-F and EM-565-F. Computer printouts of 13-mode emission results are presented in Tables A-4 and A-5 of Appendix A. The HC and CO emission rates of the Perkins 4.2032 were noticeably higher with both fuels than the Deutz F3L 912W. NO_x emission rates of the Perkins 4.2032 were only slightly higher than the Deutz F3L 912W. HC and CO emissions from the Perkins 4.2032 were slightly higher with AL-7225-F than with EM-565-F, although NO_x emission rates were higher with EM-565-F.

Two additional engines, a Deutz F4L 912W and a Perkins 4.2482, were evaluated with the EPA certification fuel. Emission rates from the EPA 13-mode tests are presented in Tables A-6 and A-7 of Appendix A. A comparison of HC, CO, and NO_x emission rates for all engine-fuel combinations is shown in Figure 8. Emission rates from the Deutz F4L 912W are quite similar to those from the

TABLE 11. SUMMARY OF 13-MODE EMISSION RESULTS FOR A DEUTZ F3L 912W OPERATED ON THREE FUELS

Fuel Code	Engine Speed	Load, %	Measured HC, ppmC	Measured CO, ppm	Measured CO_2, pct	Measured NO_x, ppm	Calculated, g/hr HC	Calculated, g/hr CO	Calculated, g/hr NO_x	g/hp-hr HC	g/hp-hr CO	g/hp-hr NO_x
EM-565-F	Idle	0	40	129	1.70	140	1	5	8	--	--	--
AL-7225-F	Idle	0	90	129	1.65	99	3	10	12	--	--	--
AL-12287-F	Idle	0	20	54	1.55	145	0	3	11	--	--	--
EM-565-F	Intermediate	2	76	191	1.95	105	1	5	8	6.67	33.28	27.86
AI-7225-F	Intermediate	2	65	125	2.20	114	4	16	22	5.26	20.05	27.52
AL-12287-F	Intermediate	2	51	125	2.10	125	2	12	20	3.08	14.91	24.92
EM-565-F	Intermediate	25	65	121	3.64	270	5	16	59	0.54	1.95	6.98
AL-7225-F	Intermediate	25	45	95	3.90	294	3	13	66	0.39	1.59	7.88
AL-12287-F	Intermediate	25	45	87	3.45	285	3	13	62	0.36	1.44	7.72
EM-565-F	Intermediate	50	58	87	5.53	445	4	11	88	0.22	0.65	5.01
AL-7225-F	Intermediate	50	50	54	5.38	387	3	7	79	0.20	0.42	4.56
AL-12287-F	Intermediate	50	52	75	5.08	405	4	10	91	0.22	0.62	5.53
EM-565-F	Intermediate	75	56	91	7.85	530	4	11	103	0.14	0.44	3.94
AL-7225-F	Intermediate	75	50	82	7.95	585	3	10	114	0.13	0.40	4.44
AL-12287-F	Intermediate	75	44	71	7.30	490	3	9	101	0.12	0.37	4.15
EM-565-F	Intermediate	100	58	293	11.45	475	4	35	89	0.11	1.02	2.56
AI-7225-F	Intermediate	100	72	151	10.25	402	5	19	79	0.14	0.55	2.33
AL-12287-F	Intermediate	100	51	169	10.86	500	4	21	102	0.11	0.65	3.12
EM-565-F	Rated	2	154	406	2.80	135	16	82	42	11.95	62.08	31.79
AL-7225-F	Rated	2	160	356	3.39	129	13	57	31	19.73	86.05	46.47
AL-12287-F	Rated	2	155	336	2.58	110	15	56	36	23.21	99.22	54.09
EM-565-F	Rated	25	96	251	4.16	220	10	49	67	0.77	3.93	5.32
AI-7225-F	Rated	25	130	255	4.30	243	13	51	76	1.27	4.84	7.17
AL-12287-F	Rated	25	91	237	3.83	210	10	48	71	0.90	4.57	6.71
EM-565-F	Rated	50	102	200	5.53	320	11	41	101	0.47	1.78	4.37
AL-7225-F	Rated	50	110	214	5.69	308	11	40	86	0.50	1.88	7.43
AL-12287-F	Rated	50	82	169	5.53	320	8	33	105	0.38	1.52	4.81
EM-565-F	Rated	75	98	182	6.59	380	11	38	122	0.33	1.18	3.76
AI-7225-F	Rated	75	113	177	7.21	470	11	34	140	0.36	1.08	4.49
AL-12287-F	Rated	75	80	155	7.67	435	8	30	136	0.24	0.89	4.11
EM-565-F	Rated	100	60	209	10.48	520	6	38	148	0.14	0.88	3.39
AI-7225-F	Rated	100	106	209	8.24	437	11	39	129	0.25	0.94	3.09
AL-12287-F	Rated	100	58	186	10.25	495	6	35	150	0.13	0.80	3.42

Deutz F3L 912W. HC and CO emission rates from the Perkins 4.2482 were significantly lower than the Perkins 4.2032; however, NO_x emission rates from the Perkins 4.2482 were noticeably higher than the Perkins 4.2032. A relative ranking of 13-mode emission rates for CO, HC and NO_x is presented in Table 12.

TABLE 12. RELATIVE 13-MODE EMISSION RANKING OF FOUR DIESEL FORKLIFT ENGINES OPERATING ON EM-565-F (g/hp-hr)

Ranking	Carbon Monoxide	Hydrocarbons	Oxides of Nitrogen
Lowest	Deutz F4L 912W	Deutz F3L 912W	Deutz F4L 912W
↓	Deutz F3L 912W	Deutz F4L 912W	Deutz F3L 912W
↓	Perkins 4.2482	Perkins 4.2482	Perkins 4.2032
Highest	Perkins 4.2032	Perkins 4.2032	Perkins 4.2482

2. Group II Emissions

Particulate, sulfate and sulfur dioxide emissions were measured on six of the 13-modes for all four engines with several fuels. Particulate emission rates are presented in Tables B-1 (g/hp-hr) and B-2 (g/hr) of Appendix B for the four engine-fuel combinations tested. The sulfur dioxide emission rates are found in Tables B-3 (g/hp-hr) and B-4 (g/hr), and sulfate emission rates are included in Tables B-5 (g/hp-hr) and B-6 (g/hr) of Appendix B. These results are summarized for two modes for particulate, sulfur dioxide, and sulfate in Tables 13 (g/hr) and 14 (g/hp-hr). The two modes are 2 percent at peak torque speed and 100 percent at rated speed. The two conditions generally represent the range of emission rates that may be produced for a given engine fuel combination.

TABLE 13. SUMMARY OF PARTICULATE, SULFUR DIOXIDE AND SULFATE EMISSION RATES FROM FOUR DIESELS WITH SEVERAL FUELS (g/hr)

Engine Model	Fuel Code	Engine Condition		Emission Rate, g/hr		
		% Load	Speed, rpm	Particulate	SO_2	Sulfate
Deutz F3L 912W	AL-7225-F	2	2650	9.70	16.48	0.404
		100	2650	11.81	51.61	1.021
Deutz F3L 912W	AL-12287-F	2	2650	6.58	62.04	0.821
		100	2650	22.27	222.79	4.018
Deutz F3L 912W	EM-565-F	2	2650	13.48	22.45	0.530
		100	2650	5.10	*	0.572
Perkins 4.2032	AL-7225-F	2	2500	21.28	15.21	0.709
		100	2500	31.56	40.12	1.422
Perkins 4.2032	EM-565-F	2	2500	30.40	27.00	0.964
		100	2500	32.18	114.52	1.677
Deutz F4L 912W	EM-565-F	2	2300	14.14	40.65	0.335
		100	2300	7.00	109.00	0.471
Perkins 4.2482	EM-565-F	2	2300	8.44	25.30	0.478
		100	2300	13.89	133.09	1.147

*Sample void

TABLE 14. SUMMARY OF PARTICULATE, SULFUR DIOXIDE AND SULFATE EMISSION RATES FROM FOUR DIESELS WITH SEVERAL FUELS (g/hp-hr)

Engine Model	Fuel Code	Engine Condition		Emission Rate, g/hp-hr		
		% Load	Speed, rpm	Particulate	SO_2	Sulfate
Deutz F3L 912W	AL-7225-F	2	2650	11.28	23.54	0.577
		100	2650	0.28	1.24	0.024
Deutz F3L 912W	AL-12287-F	2	2650	9.40	88.63	1.173
		100	2650	0.52	5.25	0.095
Deutz F3L 912W	EM-565-F	2	2650	19.26	32.07	0.757
		100	2650	0.11	*	0.013
Perkins 4.2032	AL-7225-F	2	2500	16.37	11.70	0.545
		100	2500	0.68	0.87	0.031
Perkins 4.2032	EM-565-F	2	2500	23.37	20.77	0.742
		100	2500	0.62	2.23	0.033
Deutz F4L 912W	EM-565-F	2	2300	12.30	33.87	0.291
		100	2300	0.12	1.95	0.008
Perkins 4.2482	EM-565-F	2	2300	4.89	14.88	0.281
		100	2300	0.18	1.78	0.016

*Sample void

a. Particulate

Particulate emission rates from the Deutz F3L 912W at rated speed and load ranged from 5.10 g/hr to 22.27 g/hr for the three fuels. Brake specific particulate emissions rates from the Deutz F3L 912W ranged from 0.11 g/hp-hr at rated speed and load to 19.26 g/hp-hr at 2 percent load at rated speed. The Perkins 4.2032 was higher for the Deutz F3L 912W for those tests conducted on the same fuels. In all cases, brake specific particulate emission rates were highest at the 2 percent load condition, generally ranging from 18-175 times higher than rated speed and load for those same engine fuel combinations.

Results presented in Tables B-1 and B-2 of Appendix B and Tables 13 and 14 are summarized below:

- At constant rated speed, particulate mass emission rates (g/hr) increased with increasing load.
- The 2-percent load condition produced significantly higher brake specific particulate emission rates (g/hp-hr) than higher loads.
- The Perkins 4.2032 had higher mass particulate emission rates (g/hr) than the other three engines tested, ranging from 21-33 g/hr.
- Brake specific emission rates (g/hp-hr) were higher with EM-565-F under low load conditions than AL-7225-F for both the Deutz F31 912W and the Perkins 4.2482.

b. Sulfur Dioxide

Sulfur dioxide emission rates are presented in Tables B-3 (g/hp-hr) and B-4 (g/hr) of Appendix B. The SO_2 emission rates are summarized in Tables 13

TABLE 22. EFFECT OF EXHAUST RESTRICTION ON EXHAUST EMISSIONS OF A DEUTZ F3L 912W OPERATING ON EM-565-F (EPA CERTIFICATION FUEL)

Engine Speed, rpm	Engine Load, %	Timing, °BTDC	Restriction Inlet, "H_2O	Restriction Exhaust, "Hg	BSFC, lb/hp-hr	Emission Rate, g/hp-hr HC	CO	NO_x	Part.	Smoke
Idle	0	17	12.0	1.5	--	--	--	--	--	0.4
Idle	0	17	11.8	3.1	--	--	--	--	--	0.5
Idle	0	17	12.0	6.0	--	--	--	--	--	0.5
2650	2	17	12.1	0.9	8.690	22.23	115.47	59.13	19.26	1.0
2650	2	17	13.0	1.7	9.505	27.09	132.17	63.44	13.74	2.0
2650	2	17	13.5	2.3	9.493	29.26	143.42	62.84	10.31	1.5
2650	50	17	11.9	1.4	0.530	0.47	1.68	4.37	0.53	1.4
2650	50	17	12.8	2.4	0.546	0.50	1.81	4.61	0.44	0.5
2650	50	17	12.7	4.6	0.566	0.54	1.78	4.35	0.40	2.0
2650	100	17	12.0	1.5[a]	0.472	0.14	0.88	3.39	0.13	1.8
2650	100	17	11.8	3.1	0.463	0.21	0.96	3.41	0.17	2.0
2650	100	17	12.0	6.0	0.473	0.18	1.01	3.03	0.12	3.5

[a]Standard exhaust restriction is 1.5 inches of Hg at 2650 rpm @ 100% load

TABLE 21. EFFECT OF INJECTION PUMP TIMING ON EXHAUST EMISSIONS OF A DEUTZ F3L 912W OPERATING ON EM-565-F (EPA CERTIFICATION FUEL)

Engine Speed, rpm	Engine Load, %	Timing, °BTDC	Restriction Inlet, "H_2O	Restriction Exhaust, "Hg	BSFC, lb/hp-hr	Emission Rate, g/hp-hr HC	CO	NO_x	Part.	Smoke
Idle	0	13	1.5	0.0	--	--	--	--	--	0.4
Idle	0	17[a]	1.2	0.0	--	--	--	--	--	1.0
Idle	0	21	1.5	0.0	--	--	--	--	--	0.5
Idle	0	25	1.5	0.0	--	--	--	--	--	0.5
2650	2	13	13.0	0.7	9.748	94.85	311.25	46.58	29.16[a]	2.0
2650	2	17[a]	12.1	0.9	8.690	22.23	115.47	59.13	19.26	1.0
2650	2	21	12.0	0.8	9.929	15.63	84.22	116.64	10.74	1.5
2650	2	25	13.0	0.6	9.821	19.23	95.82	133.41	12.41	1.2
2650	50	13	13.0	1.1	0.587	0.49	1.99	3.61	0.36	1.5
2650	50	17[a]	11.9	1.4	0.530	0.47	1.78	4.37	0.53	1.4
2650	50	21	12.0	1.2	0.560	0.55	1.63	7.12	0.56	1.0
2650	50	25	12.0	1.1	0.569	0.62	1.78	8.82	0.61	2.0
2650	100	13	12.0	1.4	0.506	0.15	0.90	2.93	0.18	2.5
2650	100	17[a]	12.0	1.5	0.472	0.14	0.88	3.39	0.13	1.8
2650	100	21	12.0	1.5	0.458	0.24	0.96	4.89	0.16	1.5
2650	100	25	12.0	1.4	0.471	0.31	1.43	5.69	0.33	3.0

[a]Standard injection pump timing is 17°BTDC
[b]Particulate filter appeared to be saturated with unburned fuel

100-percent load at 2650 rpm. During each mode, Group I, II, and III were obtained.

The intake air restriction was increased from standard 12.5 in. H_2O and 50 in. H_2O to simulate a plugged air filter. Exhaust restrictions were increased from the 1.5 in. Hg standard to 3.0 and 6.0 in. Hg to represent a defective or damaged exhaust system. Injection pump timing was adjusted to include 13°, 21°, 25° BTDC in addition to the standard timing of 17° BTDC.

The effects of these induced faults on HC, CO, NO_x, particulate, sulfur dioxide and sulfate are listed in Tables C-1 through C-5 of Appendix C. These effects are summarized in Tables 21, 22, and 23 for all test conditions, and general trends at rated speed and load are illustrated in Tables 24 and 25. Increasing the intake restriction from 12.5 to 25 in. H_2O had no effect on NO_x or CO at rated speed and load. A noticeable increase in particulate was observed in increasing the intake restriction under rated speed and load, i.e., more restriction, more particulate. CO increased at the 50 in. H_2O intake restriction.

At 2-percent load at rated speed, no changes in particulate or NO_x were observed with an increased intake air restriction. Both HC and CO emission rates increased at the higher intake air restrictions; although, HC increases were more pronounced.

Increased exhaust backpressures were used to simulate restricted mufflers, bent exhaust pipe, etc. The engine backpressure was increased from 1.5 in. Hg to 3.0 and 6.0 in. Hg to investigate the effect of this fault on exhaust emission rates. Under rated speed and load conditions as well as the worst case condition; no significant effect on HC, CO, NO_x and particulate emissions could be attributed to excessive engine backpressure.

The third fault included injection pump adjustments to cover the range of anticipated maladjustments that might be experienced in the field. This

- Phenanthrene and pyrene were the most prevalent PNAs detected

- Brake specific PNA emission rates were much greater at low loads for all three engines than at high loads.

- 1-nitropyrene was the highest emitted nitroaromatic, 30-60 times any of the dinitropyrene (brake specific basis)

- Brake specific 1-nitropyrene emission rates ranged from 227 μg/hp-hr at 2-percent load at 1600 rpm (worst case) to 9.4 μg/hp-hr at rated speed and load.

Other PNA Compounds tentatively identified in the GC-MS analysis are listed in Table B-13 of Appendix B.

B. Induced Faults

Emission rates from several diesel engines operating on various fuels have been reported in previous sections in this report. These data were generated with the vehicle in proper operating condition. In reality, it is conceivable that these engines could be operated (and still function satisfactorily) with engine faults or maladjustments. Typical engine faults include excessive intake air restriction (plugged air filter), increased exhaust backpressure (bent exhaust pipe, restricted muffler) or injection timing maladjustment. These three faults represent three of the more common faults typically encountered in field operation.

The use of diesel forklifts in areas with limited ventilation warrant investigation into this "worst case" situation. The Deutz F3L 912W diesel engine was selected for this evaluation and was tested over an abbreviated test matrix that included four test conditions representing the range of emission rates expected from this engine. These conditions included idle, 2-, 50-, and

TABLE 20. CONCENTRATION OF VARIOUS PNA COMPOUNDS IN ORGANIC EXTRACTABLES FROM DIESEL PARTICULATE (ppm)

Compound	Deutz F3L 912W (AL-12287-F)			Perkins 4.2032 (EM-565-F)			Deutz F4L 912W (EM-565-F)		
	Idle	2% Load 1600 rpm	100% Load 2650 rpm	Idle	2% Load 1500 rpm	100% Load 2500 rpm	Idle	2% Load 1500 rpm	100% Load 2300 rpm
Fluorene	17	20	20	440	241	41	20	20	16
Phenanthrene	690	210	660	3600	3300	2800	400	330	550
Anthracene	59	34	54	220	170	110	ND	39	55
Fluoranthene	160	330	1300	130	190	760	100	550	940
Pyrene	320	410	620	550	800	830	56	710	830
Benzo(a)anthracene	46	92	110	22	27	40	30	150	110
Chrysene	65	110	380	41	48	110	79	190	260
Benzo(b)fluoranthene	66	240	250	20	20	34	76	360	180
Benzo(a)pyrene	20	58	20	20	ND	20	ND	83	20
Indeno(1,2,3-CD)pyrene	20	50	20	ND	ND	ND	ND	66	18
Dibenzo(a,h)anthracene	ND	23	20	ND	ND	ND	ND	ND	20
Benzo(g,h,i)perylene	20	130	20	ND	ND	ND	ND	210	20
Nitropyrene	ND	ND	200	ND	ND	ND	ND	ND	600

TABLE 19. PNA EMISSION RATES FROM THREE DIESEL ENGINES (μg/hp-hr)

Compound	Deutz F3L 912W (AL-12287-F)			Perkins 4.2032 (EM-565-F)			Deutz F4L 912W (EM-565-F)		
	Idle	2% Load 1600 rpm	100% Load 2650 rpm	Idle	2% Load 1500 rpm	100% Load 2500 rpm	Idle	2% Load 1500 rpm	100% Load 2300 rpm
Fluorene	--	71	1	--	1487	1	--	58	1
Phenanthrene	--	746	16	--	20368	36	--	961	8
Anthracene	--	121	1	--	1049	1	--	114	1
Fluoranthene	--	1172	32	--	1173	10	--	1062	14
Pyrene	--	1456	15	--	4938	11	--	2069	12
Benzo(a)anthracene	--	327	3	--	167	1	--	437	2
Chrysene	--	391	9	--	296	1	--	554	4
Benzo(b)fluoranthene	--	853	6	--	123	1	--	1049	3
Benzo(a)pyrene	--	206	1	--	ND	0.3	--	242	0.3
Indeno(1,2,3-CD)pyrene	--	178	1	--	ND	ND	--	192	0.3
Dibenzo(a,h)anthracene	--	82	1	--	ND	ND	--	ND	0.3
Benzo(g,h,i)perylene	--	462	1	--	ND	ND	--	612	0.3
Nitropyrene	--	ND	5	--	ND	ND	--	ND	9

TABLE 17. SOLUBLE ORGANICS IN DIESEL PARTICULATE FROM THREE ENGINES

Engine Model	Fuel	Engine Condition Load,%	Engine Condition Speed	Percent Organic Extractables
Deutz F3L 912W	AL-12287-F	--	Idle	55.0
Deutz F3L 912W	AL-12287-F	2	1600	28.6
Deutz F3L 912W	AL-12287-F	100	2650	4.8
Perkins 4.2032	EM-565-F	--	Idle	88.5
Perkins 4.2032	EM-565-F	2	1500	90.9
Perkins 4.2032	EM-565-F	100	2500	7.1
Deutz F4L 912W	EM-565-F	--	Idle	39.0
Deutz F4L 912W	EM-565-F	2	1500	32.7
Deutz F4L 912W	EM-565-F	100	2300	12.5

TABLE 18. NITROPYRENE EMISSION RATES OF A DEUTZ F3L 912W OPERATING ON A MIL-F-46162B(ME) Fuel (AL-12287-F)

Exhaust Species	Engine Condition - Idle ng/mg particulate	µg/hour	µg/lb-fuel	µg/hp-hr
1-Nitropyrene	4.2	6.3	8.2	*
1,3-Dinitropyrene	0.2	0.3	0.4	*
1,6-Dinitropyrene	0.5	0.8	1.0	*
1,8-Dinitropyrene	0.4	0.6	0.8	*

Exhaust Species	Engine Condition - 2% Load, 1600 rpm ng/mg particulate	µg/hour	µg/lb-fuel	µg/hp-hr
1-Nitropyrene	18.3	90.4	30.7	227.3
1,3-Dinitropyrene	0.1	0.5	0.2	1.2
1,6-Dinitropyrene	0.7	3.5	1.2	8.7
1,8-Dinitropyrene	0.2	1.0	0.3	2.5

Exhaust Species	Engine Condition - 100% Load, 2650 rpm ng/mg particulate	µg/hour	µg/lb-fuel	µg/hp-hr
1-Nitropyrene	18.1	403.1	20.5	9.4
1,3-Dinitropyrene	0.2	4.5	0.2	0.1
1,6-Dinitropyrene	0.2	4.5	0.2	0.1
1,8-Dinitropyrene	0.3	6.7	0.3	0.2

*Denotes no horsepower produced at idle

TABLE 16. SUMMARY OF GROUP IV GASEOUS EMISSIONS FROM A DEUTZ F3L 912W OPERATING ON AL-12287-F

Exhaust Species		Concentration ppm	Concentration µg/m³	Emission Rate mg/hr	Emission Rate mg/hp-hr
Total cyanide	Idle	0.03	27.85	1.25	--
	2% @ 1600	0.02	21.07	2.54	3.18
	100% @ 2650	0.02	22.07	3.94	0.09
	TLV	10	--	--	--
Hydrogen sulfide	Idle	0.01	14	0.6	--
	2% @ 1600	0.01	14	1.7	2.13
	100% @ 2650	0.01	14	2.5	0.06
	TLV	10	--	--	--
Methane	Idle	1.68	1121	50	--
	2% @ 1600	2.75	1834	221	276.25
	100% @ 2650	2.67	1781	318	7.28
	TLV	None	--	--	--
Ethylene	Idle	3.00	1749	79	--
	2% @ 1600	8.27	4821	582	727.50
	100% @ 2650	11.75	6850	1222	28.96
	TLV	5500	--	--	--
Ethane	Idle	0.08	50	2	--
	2% @ 1600	0.14	88	11	13.75
	100% @ 2650	0.19	119	21	0.48
	TLV	None	--	--	--
Acetylene	Idle	0.29	157	7	--
	2% @ 1600	0.96	520	63	78.75
	100% @ 2650	1.50	813	145	3.31
	TLV	None	--	--	--
Propane	Idle	0.05	30	1	--
	2% @ 1600	0.05	30	4	5.00
	100% @ 2650	0.05	30	6	0.14
	TLV	1000	--	--	--
Propylene	Idle	0.88	513	23	--
	2% @ 1600	2.35	1370	165	206.25
	100% @ 2650	3.96	2309	412	9.43
	TLV	None	--	--	--
Benzene	Idle	0.46	249	11	--
	2% @ 1600	1.02	553	67	83.75
	100% @ 2650	1.85	1003	179	4.10
	TLV	10	--	--	--
Toluene	Idle	0.05	30	ND	--
	2% @ 1600	0.05	30	ND	ND
	100% @ 2650	0.17	93	17	0.39
	TLV	200	--	--	--

the TIA values were noticeably higher, namely the Perkins 4.2032 operating on a EM-565-F. No other trends were readily apparent.

4. Group IV Analysis

Group IV analyses included both gaseous and particulate bound organic compounds. Gaseous emissions in Group IV include hydrogen sulfide, total cyanide, and selected individual low molecular weight hydrocarbons. These results are presented in Table 16. A comparison of the gaseous emissions to Occupational Safety and Health Administration (OSHA) Threshold Limit Value (TLV) for these compounds indicates all gaseous Group IV species were well below the OSHA TLV for those compounds which have established TLVs.

The particulate bound organic materials were removed using a soxhlet extraction with methyl chloride followed by solvent evaporation in a itrogen atmosphere. The percent organic extractables in diesel particulate from three engines is presented in Table 17. The percent organic extractables generally decreased with an increase in load. These organic extractables were analyzed for nitropyrenes using an HPLC procedure and for EPA priority pollutant PNA compounds using GC-MS procedures.

The results of the nitropyrene analysis are presented in Table 18. Of the four nitropyrenes (one nitro- and three dinitro-) detected, 1-nitropyrene was by far the most predominant. The 1-nitropyrene emission rates ranged from 227 μg/hp-hr at the worst case (2-percent load) to 9.4 μg/hp-hr at rated speed and load. 1-nitropyrene mass emission rates ranged from 6.3 μg/hr at idle to 403.1 μg/hr at rated speed and load.

A GC-MS was used to quantitatively determine the presence of EPA priority pollutant PNA compounds in the organic extracts of diesel particulate from three diesel engines. The concentration of those PNA compounds quantitatively detected by GC-MS are presented in Table 19. The brake specific PNA emission rate (μg/hp-hr) is listed in Table 20. A summary of PNA and nitropyrene emission trends is listed below:

c. Organic Sulfides

Carbonyl sulfide, methyl sulfide, ethyl sulfide and dimethyldisulfide were organic sulfides included in this Group III analysis. Organic sulfide emission rates are presented in Tables B-10 (mg/hp-hr) and B-11 (mg/hr) of Appendix B. In general, the only organic sulfide which was detected in most Perkins exhaust samples was carbonyl sulfide. Other sulfides were detected only randomly and in very low concentrations. Table 15 summarizes the carbonyl sulfide brake specific emission rates. Trends observed for carbonyl sulfide are summarized below:

- No carbonyl sulfide or other organic sulfides were detected in any of the Deutz F3L 912W of Deutz F4L 912W exhaust samples with any of the fuels tested.

- In general, organic sulfides emission rates did not appear dependent on the fuel sulfur level.

- With the Perkins 4.2032, brake specific carbonyl sulfur emission rates were highest under low load condition.

- Brake specific carbonyl sulfide emission rates from the Perkins 4.2482 were less than the Perkins 4.2032.

d. DOAS Odor

Odor measurements were obtained on the four diesel engines at three of the 13 modes. These results are presented in Table B-12 of Appendix B. The DOAS odor is summarized in Table 15 for two primary modes (2 percent load at peak torque and 100 percent load at rated speed) for the engine-fuel combinations evaluated. In general, the DOAS odor levels ranged within typically experienced values (i.e., 1.5-2.0 TIA units). Only one instance occurred where

- Formaldehyde was the predominant aldehyde detected, generally accounting for 30-50 percent of the total detected.

- Brake specific formaldehyde emission rates (g/hp-hr) were highest under low load conditions.

- Formaldehyde emission rates were higher with MIL-F-46162A(MR) fuel (AL-12887-F) than the other two fuels.

- Formaldehyde emission rates (g/hp-hr and µg/hr) were significantly higher on the two Perkins engines than the Deutz engines.

b. Phenols

Phenols were measured on three of the thirteen-modes with the various engine-fuel combinations. Results of the individual modes tested for each of the engine-fuel combinations are presented in Table B-9 of Appendix B. In general, the individual phenols included in this analysis were below or near the detection limits of the analytical procedure. Consequently, only a limited amount of trend analysis can be determined, namely:

- No phenols were detected with any of the four engines with EM-565-F.

- Some phenols were detected in exhaust from the Deutz F3L 912W and Perkins 4.2032 using AL-7225-F.

- Some phenols were detected in exhaust from the Deutz F3L 912W and Perkins 4.2032 using AL-7225-F.

- No phenols were detected with the Deutz F3L 912W with AL-12287-F.

TABLE 15. SUMMARY OF MAJOR GROUP III SPECIES (FORMALDEHYDE, CARBONYL SULFIDE, DOAS ODOR) EMISSION RATES AND ODOR VALUES

Engine Model	Fuel Code	Engine Condition		Emission Rate, mg/hp-hr		DOAS Odor,
		% Load	Speed, rpm	Formaldehyde	COS	TIA Units
Deutz F3L 912W	AL-7225-F	2	1600	18	ND	1.71
		100	2650	0.4	ND	1.38
Deutz F3L 912W	AL-12287-F	2	1600	60	ND	1.95
		100	2650	0.5	ND	2.14
Deutz F3L 912W	EM-565-F	2	1600	20	ND	1.39
		100	2650	2.8	ND	2.04
Perkins 4.2032	AL-7225-F	2	1500	588	5.96	2.07
		100	2500	11.7	0.06	--
Perkins 4.2032	EM-565-F	2	1500	698	19.88	2.27
		100	2500	41.4	0.19	2.91
Deutz F4L 912W	EM-565-F	2	1500	ND	ND	1.48
		100	2300	3.2	ND	2.06
Perkins 4.2482	EM-565-F	2	1400	435	ND	1.66
		100	2300	0.8	0.06	1.87

- Brake specific sulfate emission rates (g/hp-hr) were highest at the low load conditions for all engine fuel combinations.

- Higher sulfate emissions (g/hp-hr and g/hr) were observed with the Deutz F3L 912W operating on high sulfur AL-12287-F than either AL-7225-F or EM-565-F.

3. Group III Emissions

Group III exhaust emissions include aldehydes (and ketones), organic sulfides, phenols, and DOAS odor. This section presents results of these analyses for all engine-fuel combinations tested. Results for two engines (Deutz F3L 912W and Perkins 4.2032) tested with AL-7225-F in an earlier phase of this program[1] are included for comparison purposes. The Group III analyses were conducted at three test conditions; i.e., idle, 2-percent load at peak torque speed, and 100 percent load at rated speed. The conditions were selected on a basis of a previous study to represent the range of anticipated emission rates for Group III emissions.

a. Aldehyde (and Ketone)

Aldehyde and ketone emission rates are summarized in Tables B-7 (mg/hp-hr) and B-8 (mg/hr) of Appendix B. Although Tables B-7 and B-8 present emission rates for each of the the individual aldehydes and ketones, formaldehyde is considered the best individual indicator of aldehyde trends. Formaldehyde emission rates are summarized in Table 15 for each engine-fuel combination tested. In general, these results are summarized following Table 15.

(g/hp-hr) and 14 (g/hr) for all engine fuel combinations tested. A review of this data indicates several trends, namely:

- At constant speed, sulfur dioxide mass emission rates (g/hr) increase with an increase in load. This increase is probably due to the increase in fuel rate.

- Sulfur dioxide brake specific emission rates (g/hp-hr) were highest at low loads at rated speed for all engines tested.

- Mass sulfur dioxide emission rates (g/hr) were higher with the high-sulfur containing fuel (AL-12287-F) for the Deutz F3L 912W and Perkins 4.2032 than for fuels AL-7225-F or EM-565-F.

- Sulfur dioxide emissions are a result of the fuel sulfur level and any control on sulfur dioxide emissions would have to come from reductions in fuel sulfur level rather than engine design changes.

c. Sulfate

Sulfate emission rates are presented in Tables B-5 (g/hp-hr) and B-6 (g/hr) for all engine fuel combinations tested. The sulfate emission rates are summarized in Tables 13 (g/hp-hr) and 14 (g/hr). General trends and observations for this data are summarized below:

- Sulfate mass emission rates (g/hr) were highest at the high load conditions.

- Generally, less than 5 percent of the fuel sulfur is converted to sulfate.

TABLE 23. EFFECT OF INLET AIR RESTRICTION ON EXHAUST EMISSIONS OF A DEUTZ F3L 912W OPERATING ON EM-565-F (EPA CERTIFICATION FUEL)

Engine Speed, rpm	Engine Load, %	Timing, °BTDC	Restriction Inlet, "H_2O	Restriction Exhaust, "Hg	BSFC, lb/hp-hr	Emission Rate, g/hp-hr HC	CO	NO_x	Part.	Smoke
Idle	0	17	1.2	0.1	--	--	--	--	--	0.4
Idle	0	17	3.5	0.1	--	--	--	--	--	0.5
Idle	0	17	5.0	0.0	--	--	--	--	--	0.5
2650	2	17	12.1	0.9	8.690	22.23	115.47	59.13	19.26	1.0
2650	2	17	27.7	0.8	9.037	34.02	165.53	59.63	12.92	2.5
2650	2	17	55.0	0.7	8.046	50.53	207.42	57.90	12.35	2.0
2650	50	17	11.9	1.4	0.530	0.47	1.78	4.37	0.53	1.4
2650	50	17	26.3	1.3	0.545	0.45	1.81	4.03	0.40	0.5
2650	50	17	53.0	1.1	0.518	0.44	1.67	3.55	0.33	1.0
2650	100	17	12.0[a]	1.5	0.472	0.14	0.88	3.39	0.13	1.8
2650	100	17	25.0	1.6	0.466	0.15	1.47	2.88	0.28	2.5
2650	100	17	50.0	1.3	0.460	0.13	1.31	2.81	0.30	5.0

[a]Standard intake restriction is 12.0 "H_2O at 2650 rpm @ 100% load

adjustment included 13°, 21° and 25° BTDC in addition to the standard timing of 17° BTDC. The effects of injection timing on emissions rates at all four test conditions are listed in Table 21, and are summarized in Table 24 for rated speed and load and Table 25 for 2-percent load at rated speed. No significant changes were observed in HC, CO, NO_x or particulate when the injection pump timing was adjusted to 13° BTDC when tested at rated speed and load. However, at 2-percent load, significant increases in CO and HC were observed, along with a slight increase in particulate.

No changes in CO or particulate rates were observed for an injection timing of 21° BTDC, although a slight increase in NO_x emission rates was observed at 2-percent load. CO emission rates also slightly increased at rated speed and load at 21° BTDC. When the injection pump timing was adjusted to 25° BTDC, both CO and NO_x showed slight increases while particulate emission rates increased significantly (at rated speed and load). At 2-percent load, no changes in HC, CO and particulate were observed; however, a significant increase in NO_x was observed.

Under Bureau of Mines Contract H0292009 to Southwest Research Institute, a more detailed investigation of the effect of induced faults on emissions was conducted. This study involved a Deutz F6L 912W operated over a wider range of induced faults and various combinations of induced faults. In general, effects of various induced faults on the Deutz F6L 912W agreed reasonably well with data reported in this study on the Deutz F3L 912W. The results illustrating the effect of individual induced faults and combinations of induced faults on a Deutz F6L 912W are found in Table 26. As a result of the two studies involving induced faults on two Deutz 912W series engines, the following general trends were observed.

1. Exhaust restriction - little or no effect on HC, CO, NO_x or particulate.

2. Intake restriction - little or no effect on HC, CO and NO_x, particulate increased at high (50 in. H_2O) intake air restriction.

TABLE 24. EFFECT OF INDUCED FAULTS ON GASEOUS AND PARTICULATE EMISSION RATES: ARROWS INDICATE CHANGE FROM BASELINE AT 100% LOAD AT RATED SPEED ON DEUTZ F3L 912W WITH EM-565-F

Fault Description		HC	CO	NO_x	Particulate
Intake Restriction (12.5 in. H_2O is standard	25	→	→	→	↗
	50	→	↗	→	↑
Exhaust Restriction (1.5 in. Hg is standard)	3.0	→	→	→	→
	6.0	→	→	→	→
Injection Timing (17°BTDC is standard)	13°	→	→	→	→
	21°	↗	→	→	→
	25°	↑	↗	↗	↑

↑ indicates >200% increase above baseline
↗ indicates 50% to 200% increase
→ indicates <50% increase

TABLE 25. EFFECT OF INDUCED FAULTS ON GASEOUS AND PARTICULATE EMISSION RATES: ARROWS INDICATE CHANGE FROM BASELINE AT 2 PERCENT LOAD AT RATED SPEED ON DEUTZ F3L 912W WITH EM-565-F

Fault Description		HC	CO	NO_x	Particulate
Intake Restriction (12.5 in. H_2O is standard)	25	↗	→	→	→
	50	↑	↗	→	→
Exhaust Restriction (1.5 in. Hg is standard)	3.0	→	→	→	→
	6.0	→	→	→	→
Injection Timing (17°BTDC is standard)	13°	↑	↑	→	↗
	21°	→	→	↗	→
	25°	→	→	↑	→

↑ indicates >200% increase above baseline
↗ indicates 50% to 200% increase
→ indicates <50% increase

TABLE 26. EFFECT OF FAULTS AND MALADJUSTMENTS ON DIESEL ENGINE EXHAUST COMPOSITION: ARROWS INDICATE CHANGE FROM BASELINE[5]

NO.	FAULT DESCRIPTION		HC	CO	NO_x	PART.*
1-1	Intake Restriction (in - H_2O)	25	→	→	→	→
1-2		50	→	→	→	↗
2-1	Exhaust Restriction (in - Hg)	3.0	→	→	→	→
2-2		6.0	→	→	→	→
3-1	Timing Advance (from Mfg. Spec.)	-4°	↑	↗	→	↑
3-2		+4°	↗	→	→	→
3-3		+8°	↗	→	↗	→
4-1	Overfueling (% rated)	10%	→	↗	→	↗
4-2		20%	→	↑	→	↗
5-1	Intake Restriction Timing Advance	25 -4°	↗	→	→	↗
5-2		50 -4°	↑	↗	→	↑
6-1	Exhaust Restriction Timing Advance	3.0 +4°	↗	→	→	→
6-2		6.0 +8°	→	→	↗	↗
7-1	Intake Restriction Overfueling	25 10%	→	↗	→	↗
7-2		50 20%	→	↑	→	↑
8-1	Overfueling Timing Advance	10% +4°	→	↗	→	↗
8-2		20% +8°	→	↗	→	↑
9-1	Intake Restriction Exhaust Restriction	25 3.0	→	→	→	→
9-2		50 6.0	→	↗	→	↗
10-1	Exhaust Restriction Overfueling	3.0 10%	→	↗	→	↑
10-2		6.0 20%	→	↑	→	↑
11-1	Int., Exh. Restric. Overfuel, Timing Adv.	25,3.0 10%,+4°	→	↗	→	↑
11-2		50,6.0 20%,+8°	→	↑	→	↑

*This represents particulate production at the most severe engine operating mode.

↑ indicates > 200% increase above baseline
↗ indicates 50% to 200% increase
→ indicates < 50% increase

3. Timing advance - at 13° BTDC, HC and particulate increased significantly, CO increased slightly with no change in NO_x observed for the Deutz F6L 912W. Little or no changes in CO, HC, NO_x or particulate observed with Deutz F3L 912W at 13° BTDC. HC and particulate increased significantly at 25° BTDC for both engines, NO_x increased slightly for both engines.

4. Overfueling - HC and NO_x were essentially unaffected, CO and particulate both increased with the Deutz F6L 912W.

5. Combinations of 1-4 above - In general, most combinations of induced faults on the Deutz F6L 912W produced increased CO and particulate. In most cases, little or no effect on HC and NO_x emissions was observed. (HC exception was intake restriction at 13° BTDC, NO_x exception exhaust restriction at 25° BTDC).

The effects of induced faults on unregulated emissions (Groups II and III) were also determined. For relative comparison purposes, particulate results were included with Group I. The worst case condition for the effects of engine faults on Groups II and III emissions was observed at 2-percent load at rated speed. Although the trends generally hold for other test conditions, only the 2-percent load is discussed. The emission rates for Groups II and III are included in Tables C-6 through C-10 of Appendix C in the event additional data analysis is desired.

A summary of four primary aldehyde emission rates (formaldehyde acetaldehyde, acrolein, and benzaldehyde) as a function of increased intake air, increased backpressure and maladjusted injection pump timing is presented in Table 27. In general, aldehyde emission rates increase with any adjustment from the standard. In two instances, 50 in. H_20 intake air restriction and 13° BTDC injection pump timing produced very significant increases in quantities of aldehyde emission rates, greater than 1000 percent increase over baseline

conditions. These increases could conceivably be higher if the two faults occurred simultaneously.

TABLE 27. EFFECT OF INDUCED FAULTS ON ALDEHYDE EMISSION RATES: ARROWS INDICATE CHANGE FROM BASELINE UNDER WORST CASE CONDITION (2 PERCENT LOAD AT RATED SPEED) ON DEUTZ F3L 912 W WITH EM-565-F

Fault Description		Formaldehyde	Acetaldehyde	Acrolein	Benzaldehyde
Intake Restriction (12.5 in. H_2O is standard)	25	↑	↑	→	↗
	50	↑↑	↑↑	↑	↑
Exhaust Restriction (1.5 in. Hg is standard)	3.0	↗	↑	↑	→
	6.0	↗	↑	→	↑
Injection Timing (17°BTDC is standard)	13°	↑↑	↑↑	↑↑	↑↑
	21°	↘	↘	↘	→
	25°	→	↗	↘	→

↑ indicates >200% increase from baseline
↗ indicates 50% to 200% increase
→ indicates <50% increase
↑↑ indicates >1000% increase

The nature of this program did not allow projecting emission exposures under various ventilation or emission rate senarios; but the high aldehyde emission rates under these induced faults should be included in any future modeling studies or exposure estimates. An example of these increases is best illustrated by comparing the formaldehyde emission rate under standard conditions (125 mg/hp-hr) to the emission rate at 50 in. H_2O (2000 mg/hp-hr) and 13° BTDC (7300 mg/hp-hr). Similar increases were observed on other aldehydes under these same induced fault conditions. Additional analysis of the aldehyde emission rates should be made to ensure that exposure to diesel exhaust under typical fault conditions does not pose any health threat to personnel.

Other emissions that were investigated during these induced faults tests included sulfur dioxide, sulfate, organic sulfides, and phenols. The emission rates for sulfur dioxide, sulfate, and organic sulfides for the induced fault tests are included in Appendix C, and the effect of induced faults on these emissions is summarized in Table 28. These emissions were found to be essentially insensitive to the induced faults.

C. Trend Validation

Validation of Group I emission trends was accomplished on several engine-fuel combinations to confirm emission trends reported in an earlier phase. The emission trends reported earlier are presented in Figures 9 and 10 for the Deutz F3L 912W and Perkins 4.2032 operating on AL-7225-F. Trend validation was accomplished on the Deutz F3L 912W with AL-12287-F (MIL-F-46162B(ME), Perkins 4.2482 and Deutz F4L 912W operating on EM-565-F, the EPA certification fuel.

Six modes of the EPA 13-mode cycle were selected to confirm emission trends. These modes included 2-, 50-, and 100-percent load at rated speed, 2- and 25-percent at peak torque speed and idle. These six modes include the worst case conditions, i.e. 2 percent load at both speeds. In general, as load is applied,

TABLE 28. EFFECT OF INDUCED FAULTS ON UNREGULATED EMISSIONS (SULFUR DIOXIDE, SULFATE, ORGANIC SULFIDES AND PHENOLS) FROM A DEUTZ F3L 912W WITH EM-565-F UNDER WORST CASE CONDITION (2 PERCENT LOAD AT RATED SPEED)

Fault Description		SO_2	$SO_4^{=}$	Organic Sulfides	Phenols
Intake Restriction (12.5 in. H_2O is standard)	25	→	→	→	→
	50	→	→	→	→
Exhaust Restriction (1.5 in. Hg is standard)	3.0	→	→	→	→
	6.0	→	→	→	→
Injection Timing (17°BTDC is standard)	13°	→	→	→	→
	21°	→	→	→	→
	25°	→	→	→	→

↑ indicates >200% increase from baseline
↗ indicates 50% to 200% increase
→ indicates <20% increase

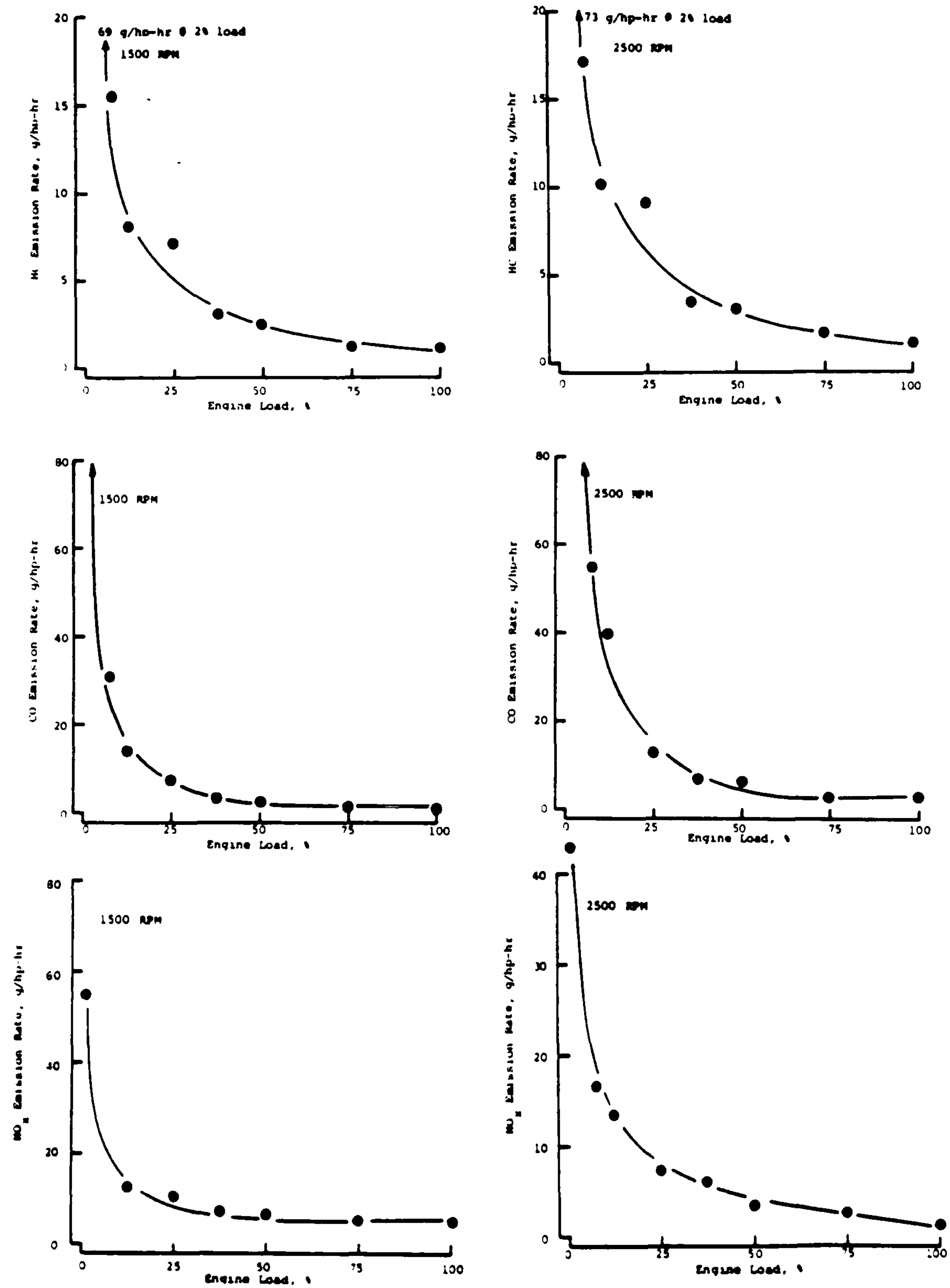


FIGURE 9. THE EFFECT OF ENGINE LOAD ON HYDROCARBONS, CARBON MONOXIDE, AND OXIDES OF NITROGEN EMISSION RATES FROM A PERKINS 4.2032 AT TWO ENGINE SPEEDS

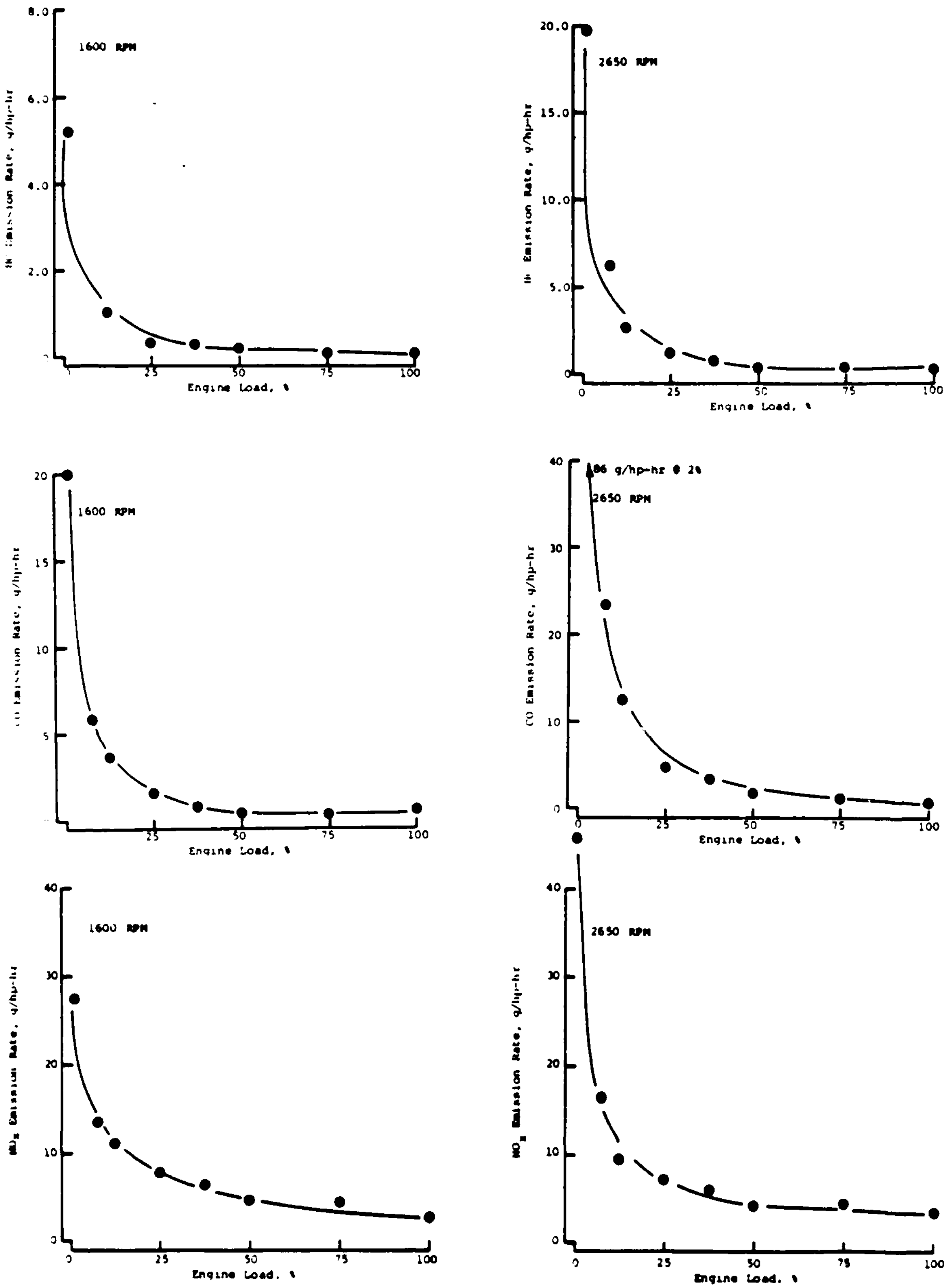


FIGURE 10. THE EFFECT OF ENGINE LOAD ON HYDROCARBONS, CARBON MONOXIDE, AND OXIDES OF NITROGEN EMISSION RATES FROM A DEUTZ F3L 912W AT TWO ENGINE SPEEDS

emission rates (g/hp-hr) decreased quite rapidly. During the validation of emission trends, triplicate tests were conducted with each engine-fuel combination.

Results of the trend validation tests are summarized in Tables 29, 30, and 31. The trends were confirmed to the extent that at low load (i.e., 2-percent) brake specific emissions rates were high. However, once load was applied to the engine, brake specific emission rates were reduced drastically. This trend was observed for both rated and peak torque speeds.

In comparing mass emission rates, general trends on all three engines were also confirmed. As the load increased, CO emissions decreased at both peak torque and rated speeds. NO_x mass emission rates increased as the engine load increased for a given engine speed. Results observed with these three engine-fuel combinations confirm trends reported in earlier work.[1]

TABLE 29. TREND VALIDATION OF EMISSIONS FROM PERKINS 4.2482 WITH EPA CERTIFICATION FUEL, EM-565-F

Load, %	Speed, rpm	Run	Measured Concentrations HC, ppmC	CO, ppm	CO_2, %	NO_x, ppm	Mass Emission Rate, g/hr HC	CO	NO_x	Brake Specific Emission Rate, g/hp-hr HC	CO	NO_x	Fuel Specific Emission Rate, g/lb fuel HC	CO	NO_x
2	1400	1	396	307	1.75	180	33	51	44	31.53	48.67	41.84	10.03	15.49	13.31
		2	444	298	1.70	185	39	52	52	37.41	49.94	49.61	11.55	15.42	15.32
		3	444	298	1.80	180	37	50	49	37.45	47.28	46.66	10.95	14.60	14.41
		Avg	428	301	1.75	182	36	51	48	35/47	48.63	46.04	10.84	15.17	14.35
25	1400	1	396	265	3.52	465	34	45	116	2.57	3.37	8.71	5.17	6.79	17.54
		2	448	265	3.45	440	39	46	118	2.96	3.43	8.89	5.96	6.91	17.91
		3	432	265	3.52	455	37	45	126	2.80	3.36	9.51	5.65	6.78	19.16
		Avg	425	265	3.50	453	37	45	119	2.78	3.39	9.04	5.59	6.83	18.20
2	2300	1	424	437	2.20	180	54	111	68	31.38	64.11	39.70	8.59	17.55	10.87
		2	412	447	2.25	180	52	112	72	30.36	65.19	41.79	8.18	17.57	11.26
		3	416	442	2.25	190	54	113	81	31.15	65.47	47.08	8.27	17.38	12.49
		Avg	417	442	2.23	183	53	112	73	30.96	64.92	42.86	8.35	17.50	11.54
50	2300	1	246	288	5.93	555	32	72	208	0.86	1.94	5.56	1.97	4.42	12.67
		2	324	288	5.85	555	44	74	229	1.17	1.99	6.12	2.62	4.47	13.79
		3	336	288	5.85	520	44	72	211	1.18	1.94	5.64	2.72	4.47	13.02
		Avg	302	288	5.88	543	40	73	216	1.07	1.96	5.77	2.44	4.45	13.16
100	2300	1	182	341	10.96	1575	24	82	574	0.32	1.09	7.63	0.82	2.84	19.81
		2	216	303	10.37	1575	29	75	614	0.39	1.02	8.34	1.03	2.67	21.93
		3	170	293	10.84	1560	21	66	545	0.27	0.87	7.18	0.78	2.47	20.49
		Avg	189	312	10.[illegible]2	1570	25	74	578	0.33	1.13	7.72	0.88	2.67	20.74
Idle	670	1	264	185	1.47	203	10	13	21	--	--	--	8.43	11.29	17.84
		2	284	191	1.47	185	11	15	23	--	--	--	8.56	11.56	17.92
		3	284	195	1.51	190	11	15	23	--	--	--	8.40	11.50	17.86
		Avg	277	190	1.48	193	11	14	22	--	--	--	8.46	11.45	17.87

TABLE 30. TREND VALIDATION OF EMISSIONS FROM DEUTZ F4L 912W WITH EPA CERTIFICATION FUEL, EM-565-F

			Measured Concentrations				Mass Emission Rate, g/hr			Brake Specific Emission Rate, g/hp-hr			Fuel Specific Emission Rate, g/lb fuel		
Load, %	Speed, rpm	Run	HC, ppmC	CO, ppm	CO_2, %	NO_x, ppm	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
2	1500	1	60.0	160.0	1.85	110.0	5.0	27.0	30.0	6.92	36.64	40.48	1.48	7.85	8.67
		2	54.0	134.0	1.95	122.0	4.0	22.0	30.0	5.92	29.18	39.73	1.27	6.25	8.51
		3	62.0	151.0	2.00	122.0	5.0	25.0	30.0	6.82	32.94	40.10	1.42	6.86	8.36
		Avg	58.7	148.3	1.93	118.0	4.7	25.3	30.0	6.55	32.92	40.10	1.39	6.99	8.51
25	1500	1	58.0	121.0	3.45	285.0	5.0	21.0	76.0	0.46	1.89	7.02	0.78	3.21	11.93
		2	65.0	100.0	3.58	315.0	5.0	16.0	76.0	0.48	1.46	6.97	0.85	2.55	12.22
		3	60.0	100.0	3.59	285.0	5.0	16.0	67.0	0.45	1.46	6.13	0.83	2.70	11.30
		Avg	61.0	107.0	3.54	295.0	5.0	17.7	73.0	0.46	1.60	6.70	0.82	2.82	11.82
2	2300	1	260.0	452.0	2.31	100.0	32.0	110.0	36.0	27.76	95.50	31.68	5.07	17.43	5.78
		2	206.0	341.0	2.41	119.0	25.0	85.0	42.0	21.94	71.80	36.81	3.88	12.71	6.51
		3	190.0	366.0	2.41	110.0	25.0	89.0	39.0	20.23	77.06	33.81	3.58	13.63	5.98
		Avg	218.7	386.3	2.38	113.0	27.3	94.7	39.0	23.31	81.45	34.10	4.18	14.59	6.09
50	2300	1	81.0	160.0	5.53	350.0	10.0	37.0	122.0	0.34	1.29	4.25	0.70	2.65	8.73
		2	116.0	147.0	5.61	390.0	15.0	36.0	144.0	0.51	1.24	5.02	0.98	2.40	9.69
		3	116.0	151.0	5.85	370.0	14.0	34.0	128.0	0.48	1.19	4.45	0.94	2.36	8.82
		Avg	104.3	152.7	5.66	370.0	13.0	36.3	131.3	0.44	1.24	4.57	0.87	2.47	9.08
100	2300	1	68.0	255.0	10.96	485.0	8.0	56.0	164.0	0.14	0.98	2.89	0.31	2.13	6.29
		2	100.0	317.0	11.20	460.0	11.0	67.0	151.0	0.20	1.19	2.68	0.45	2.59	5.84
		3	88.0	264.0	10.96	475.0	10.0	56.0	155.0	0.18	1.01	2.81	0.40	2.21	6.12
		Avg	85.3	278.7	11.04	473.3	9.7	59.7	156.7	0.17	1.06	2.79	0.39	2.31	6.08
Idle		1	27.0	63.0	1.61	215.0	1.0	4.0	21.0	--	--	--	0.77	3.57	19.12
		2	16.0	67.0	1.65	215.0	1.0	4.0	22.0	--	--	--	0.45	3.71	18.62
		3	22.0	71.0	1.70	210.0	1.0	5.0	20.0	--	--	--	0.59	3.82	16.81
		Avg	21.7	63.7	1.65	213.3	1.0	4.3	21.0	--	--	--	0.60	3.70	18.18

TABLE A-7. COMPUTER PRINTOUT OF 13-MODE EMISSIONS TEST ON PERKINS 4.2482 ON EPA CERTIFICATION FUEL (EM-565-F)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: PERKINS 4.2482
TEST-1 FUEL: EM-565-F PROJECT: 05-6800-175 DATE: 12/07/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 675.	0.	.0	.020	3.10	24.	.889	260.	186.	1.47	200.	9.	14.	21.	1
2	2	INTER / 1400.	4.	1.1	.055	6.88	26.	.899	396.	307.	1.75	180.	33.	51.	44.	2
3	25	INTER / 1400.	50.	13.3	.110	6.80	26.	.903	396.	265.	3.52	465.	34.	45.	116.	3
4	50	INTER / 1400.	100.	26.6	.175	6.71	26.	.908	336.	191.	5.77	1080.	29.	32.	265.	4
5	75	INTER / 1400.	150.	39.9	.243	6.59	28.	.917	264.	142.	8.34	1980.	22.	23.	474.	5
6	100	INTER / 1400.	200.	53.2	.332	6.36	26.	.925	234.	1132.	11.70	2100.	20.	175.	489.	6
7		IDLE / 678.	0.	.0	.018	3.05	21.	.873	274.	191.	1.47	200.	9.	13.	19.	7
8	100	RATED / 2300.	172.	75.3	.483	10.01	28.	.924	182.	341.	10.96	1575.	24.	82.	574.	8
9	75	RATED / 2300.	127.	55.8	.370	10.37	28.	.917	180.	227.	8.14	1065.	24.	57.	397.	9
10	50	RATED / 2300.	85.	37.4	.273	10.36	28.	.911	246.	288.	5.93	555.	32.	72.	208.	10
11	25	RATED / 2300.	43.	19.0	.183	10.36	32.	.916	348.	371.	3.90	280.	45.	94.	106.	11
12	2	RATED / 2300.	4.	1.7	.105	10.36	34.	.921	424.	437.	2.20	180.	54.	111.	68.	12
13		IDLE / 656.	0.	.0	.020	3.01	28.	.900	300.	182.	1.47	210.	11.	13.	22.	13

MODE	CALCULATED GRAMS/LB-FUEL HC	CALCULATED GRAMS/LB-FUEL CO	CALCULATED GRAMS/LB-FUEL NOX	CALCULATED GRAMS/BHP-HR HC	CALCULATED GRAMS/BHP-HR CO	CALCULATED GRAMS/BHP-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR LB/HP-HR	MODAL WEIGHT FACTOR	MODE
1	7.90	11.28	17.60	******	******	******	.0065	.0690	.094	.986	.0072	11.0	.974	*****	.067	1
2	10.03	15.49	13.31	31.54	48.67	41.84	.0080	.0690	.116	.983	.0086	7.5	.987	3.184	.080	2
3	5.17	6.79	17.54	2.57	3.37	8.71	.0162	.0690	.235	.968	.0169	3.8	.987	.503	.080	3
4	2.76	3.01	25.25	1.09	1.19	9.97	.0262	.0690	.379	.949	.0271	3.6	.987	.400	.080	4
5	1.54	1.56	32.48	.56	.57	11.89	.0370	.0690	.537	.929	.0386	4.1	.988	.370	.080	5
6	.99	8.78	24.59	.37	3.29	9.20	.0524	.0690	.759	.903	.0537	2.5	.988	.378	.080	6
7	8.31	11.57	17.26	******	******	******	.0060	.0690	.087	.986	.0072	19.3	.977	*****	.067	7
8	.82	2.84	19.81	.32	1.09	7.63	.0485	.0690	.702	.909	.0501	3.4	1.000	.385	.080	8
9	1.07	2.55	17.89	.43	1.01	7.12	.0358	.0690	.519	.930	.0377	5.1	1.001	.398	.080	9
10	1.97	4.42	12.67	.86	1.94	5.56	.0265	.0690	.384	.948	.0278	5.1	1.001	.438	.080	10
11	4.12	8.58	9.68	2.39	4.97	5.61	.0178	.0690	.258	.964	.0186	4.9	1.002	.578	.080	11
12	8.59	17.55	10.87	31.38	64.11	39.70	.0102	.0690	.148	.979	.0108	6.2	1.001	3.647	.080	12
13	9.09	11.01	18.67	******	******	******	.0067	.0690	.097	.985	.0072	7.8	.975	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = 1.060 GRAM/BHP-HR
BSCO ------- = 2.396 GRAM/BHP-HR
BSNOX ------ = 8.647 GRAM/BHP-HR
BSHC + BSNOX = 9.707 GRAM/BHP-HR
CORR. BSFC - = .444 LBS/BHP-HR

DEUTZ F4L 912W ON EPA CERTIFICATION FUEL (EM-565-F)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: DEUTZ MODEL F4L912W S/N 6501447
TEST-1 FUEL: EM-565-F PROJECT: 05-6800-175

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 630.	0.	.0	.018	2.74	52.	.961	27.	63.	1.61	215.	1.	4.	21.	1
2	2	INTER / 1500.	3.	.8	.058	6.87	58.	.985	60.	160.	1.85	110.	5.	27.	30.	2
3	25	INTER / 1500.	38.	10.9	.107	6.80	53.	.969	58.	121.	3.45	285.	5.	21.	76.	3
4	50	INTER / 1500.	76.	21.8	.157	6.70	47.	.949	62.	87.	5.30	430.	5.	14.	108.	4
5	75	INTER / 1500.	113.	32.3	.215	6.56	36.	.923	58.	87.	7.85	550.	5.	13.	125.	5
6	100	INTER / 1500.	151.	43.1	.298	6.38	45.	.950	74.	200.	11.20	540.	6.	29.	123.	6
7		IDLE / 651.	0.	.0	.018	2.69	46.	.938	27.	54.	1.56	205.	1.	3.	20.	7
8	100	RATED / 2300.	130.	56.9	.435	8.95	45.	.951	68.	255.	10.96	485.	8.	56.	164.	8
9	75	RATED / 2300.	97.	42.6	.323	9.15	46.	.943	66.	151.	7.76	490.	8.	35.	173.	9
10	50	RATED / 2300.	66.	28.8	.233	9.34	42.	.924	81.	160.	5.53	350.	10.	37.	122.	10
11	25	RATED / 2300.	33.	14.4	.162	9.53	37.	.905	136.	303.	3.64	210.	17.	73.	75.	11
12	2	RATED / 2300.	3.	1.2	.105	9.73	44.	.919	260.	452.	2.31	100.	32.	110.	36.	12
13		IDLE / 625.	0.	.0	.020	2.71	51.	.947	44.	104.	1.65	220.	1.	7.	23.	13

MODE	CALCULATED GRAMS/LB-FUEL HC	CALCULATED GRAMS/LB-FUEL CO	CALCULATED GRAMS/LB-FUEL NOX	CALCULATED GRAMS/BHP-HR HC	CALCULATED GRAMS/BHP-HR CO	CALCULATED GRAMS/BHP-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR LB/HP-HR	MODAL WEIGHT FACTOR	MODE
1	.77	3.57	19.12	******	******	******	.0067	.0690	.098	.983	.0077	13.9	.974	*****	.067	1
2	1.48	7.85	8.67	6.92	36.64	40.48	.0086	.0690	.124	.981	.0089	3.5	.991	4.711	.080	2
3	.78	3.21	11.93	.46	1.89	7.02	.0158	.0690	.229	.967	.0163	3.1	.990	.594	.080	3
4	.56	1.50	11.51	.24	.65	4.98	.0235	.0690	.341	.952	.0248	5.3	.991	.436	.080	4
5	.36	1.02	9.68	.14	.41	3.87	.0330	.0690	.478	.932	.0363	10.0	.996	.402	.080	5
6	.33	1.64	6.85	.14	.68	2.84	.0471	.0690	.682	.906	.0510	8.4	.995	.417	.080	6
7	.79	3.16	18.38	******	******	******	.0069	.0690	.099	.984	.0074	8.4	.976	*****	.067	7
8	.31	2.13	6.29	.14	.98	2.89	.0489	.0690	.709	.908	.0500	2.2	1.008	.455	.080	8
9	.41	1.78	8.90	.19	.81	4.06	.0356	.0690	.516	.933	.0359	.9	1.010	.451	.080	9
10	.70	2.65	8.73	.34	1.29	4.25	.0251	.0690	.364	.951	.0259	2.9	1.011	.482	.080	10
11	1.73	7.55	7.74	1.17	5.10	5.22	.0171	.0690	.247	.966	.0173	1.5	1.012	.667	.080	11
12	5.07	17.43	5.78	27.76	95.50	31.68	.0109	.0690	.157	.977	.0113	3.6	1.011	5.419	.080	12
13	1.22	5.74	18.77	******	******	******	.0074	.0690	.108	.983	.0079	6.0	.979	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = .409 GRAM/BHP-HR
BSCO ------- = 1.691 GRAM/BHP-HR
BSNOX ------ = 4.302 GRAM/BHP-HR
BSHC + BSNOX = 4.711 GRAM/BHP-HR
CORR. BSFC - = .507 LBS/BHP-HR

TABLE A-5. COMPUTER PRINTOUT OF 13-MODE EMISSIONS TEST ON PERKINS 4.2032 ON EPA CERTIFICATION FUEL (EM-565-F)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE:PERKINS MODEL 4.203.2   13 MODE
TEST-1   FUEL:EM-565-F   PROJECT:05-6800-175   DATE:07/26/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 600.	0.	.0	.013	2.13	46.	.914	684.	313.	1.56	165.	15.	14.	11.	1
2	2	INTER / 1500.	3.	.8	.048	5.81	47.	.924	720.	741.	1.85	210.	48.	99.	42.	2
3	25	INTER / 1500.	34.	9.8	.090	5.88	45.	.925	748.	522.	3.39	540.	54.	74.	115.	3
4	50	INTER / 1500.	68.	19.5	.140	5.85	46.	.938	764.	371.	5.38	795.	56.	52.	171.	4
5	75	INTER / 1500.	105.	30.0	.192	5.75	42.	.934	640.	304.	7.76	990.	46.	41.	203.	5
6	100	INTER / 1500.	137.	39.0	.258	5.67	42.	.944	568.	470.	10.72	1200.	41.	62.	243.	6
7		IDLE / 600.	0.	.0	.013	2.14	43.	.910	848.	304.	1.51	170.	19.	14.	11.	7
8	100	RATED / 2500.	110.	52.5	.358	8.18	43.	.946	520.	860.	10.48	720.	52.	160.	207.	8
9	75	RATED / 2500.	83.	39.4	.302	8.23	50.	.954	338.	501.	8.24	545.	36.	100.	169.	9
10	50	RATED / 2500.	55.	26.3	.208	8.23	52.	.956	748.	673.	5.69	410.	77.	132.	126.	10
11	25	RATED / 2500.	28.	13.1	.142	8.23	50.	.949	816.	884.	3.83	435.	82.	172.	131.	11
12	2	RATED / 2500.	3.	1.3	.090	8.04	45.	.934	1064.	1104.	2.47	175.	99.	204.	49.	12
13		IDLE / 600.	0.	.0	.013	2.14	45.	.918	880.	304.	1.61	155.	19.	13.	10.	13

MODE	CALCULATED GRAMS/LB-FUEL HC	CALCULATED GRAMS/LB-FUEL CO	CALCULATED GRAMS/LB-FUEL NOX	CALCULATED GRAMS/BHP-HR HC	CALCULATED GRAMS/BHP-HR CO	CALCULATED GRAMS/BHP-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR LB/HP-HR	MODAL WEIGHT FACTOR	MODE
1	19.00	17.31	13.61	******	******	******	.0063	.0690	.091	.983	.0079	25.1	.997	*****	.067	1
2	16.67	34.08	14.57	64.46	131.77	56.33	.0084	.0690	.121	.981	.0095	12.9	1.014	3.815	.080	2
3	9.96	13.62	21.27	5.52	7.55	11.78	.0154	.0690	.223	.968	.0166	7.6	1.012	.547	.080	3
4	6.63	6.20	20.33	2.85	2.67	8.76	.0241	.0690	.349	.951	.0256	6.4	1.010	.426	.080	4
5	3.96	3.55	17.64	1.52	1.36	6.76	.0335	.0690	.486	.933	.0363	8.1	1.010	.380	.080	5
6	2.61	3.99	15.68	1.04	1.58	6.23	.0458	.0690	.664	.910	.0493	7.7	1.009	.394	.080	6
7	24.03	17.17	14.25	******	******	******	.0063	.0690	.091	.984	.0077	23.0	.995	*****	.067	7
8	2.44	7.44	9.61	1.00	3.05	3.93	.0441	.0690	.639	.911	.0485	9.9	1.026	.399	.080	8
9	1.98	5.53	9.36	.91	2.54	4.30	.0369	.0690	.535	.928	.0383	3.9	1.026	.448	.080	9
10	6.13	10.59	10.06	2.92	5.04	4.79	.0255	.0690	.370	.948	.0272	6.6	1.027	.464	.080	10
11	9.59	20.29	15.45	6.21	13.14	10.01	.0173	.0690	.251	.964	.0188	8.5	1.025	.632	.080	11
12	18.40	37.71	9.11	79.49	162.90	39.35	.0113	.0690	.163	.975	.0127	12.8	1.025	4.213	.080	12
13	23.48	16.14	12.33	******	******	******	.0063	.0690	.091	.983	.0082	31.1	.995	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = 2.740 GRAM/BHP-HR
BSCO ------- = 4.879 GRAM/BHP-HR
BSNOX ------ = 6.406 GRAM/BHP-HR
BSHC + BSNOX = 9.146 GRAM/BHP-HR
CORR. BSFC - = .474 LBS/BHP-HR

TABLE A-4. COMPUTER PRINTOUT OF 13-MODE EMISSIONS TEST ON PERKINS 4.2032 ON MIL-F-46162A(MR) (AL-7225-F)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: PERKINS MODEL 4.203.2   13-MODE
TEST-1   FUEL: EM-544-F   PROJECT: 05-6800-175   DATE: 3/2/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 750.	0.	.0	.015	2.74	39.	.889	824.	437.	1.51	128.	21.	22.	9.	1
2	2	INTER / 1500.	3.	.8	.050	5.68	47.	.918	720.	624.	1.80	195.	52.	89.	42.	2
3	25	INTER / 1500.	34.	9.8	.093	5.66	56.	.974	960.	494.	3.45	447.	70.	71.	102.	3
4	50	INTER / 1500.	68.	19.5	.140	5.62	53.	.951	728.	361.	5.46	675.	52.	50.	145.	4
5	75	INTER / 1500.	104.	29.6	.200	5.81	49.	.950	540.	274.	7.67	785.	41.	39.	173.	5
6	100	INTER / 1500.	129.	36.8	.240	5.55	64.	.982	620.	303.	9.69	859.	45.	41.	186.	6
7		IDLE / 750.	0.	.0	.015	2.74	39.	.889	824.	437.	1.51	128.	21.	22.	9.	7
8	100	RATED / 2500.	97.	46.3	.342	8.07	58.	.970	464.	790.	9.69	482.	48.	152.	146.	8
9	75	RATED / 2500.	81.	38.8	.300	8.19	52.	.961	592.	494.	7.85	402.	65.	103.	131.	9
10	50	RATED / 2500.	53.	25.0	.220	8.05	56.	.963	704.	790.	5.69	273.	76.	164.	89.	10
11	25	RATED / 2500.	26.	12.5	.158	8.13	61.	.987	1104.	828.	4.10	273.	115.	168.	89.	11
12	2	RATED / 2500.	3.	1.3	.097	8.15	63.	1.000	912.	1348.	2.47	167.	91.	266.	54.	12
13		IDLE / 750.	0.	.0	.015	2.74	39.	.889	824.	437.	1.51	128.	21.	22.	9.	13

MODE	CALCULATED GRAMS/LB-FUEL HC	CALCULATED GRAMS/LB-FUEL CO	CALCULATED GRAMS/LB-FUEL NOX	GRAMS/BHP-HR HC	GRAMS/BHP-HR CO	GRAMS/BHP-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR LB/HP-HR	MODAL WEIGHT FACTOR	MODE
1	23.20	24.52	10.42	******	******	******	.0055	.0690	.080	.984	.0078	41.1	1.008	*****	.067	1
2	17.19	29.61	13.86	68.76	118.45	55.43	.0089	.0690	.128	.981	.0092	3.6	1.032	3.875	.080	2
3	12.51	12.61	18.14	7.19	7.24	10.42	.0166	.0690	.241	.967	.0169	1.9	1.024	.561	.080	3
4	6.23	5.95	17.28	2.69	2.56	7.44	.0251	.0690	.364	.951	.0260	3.5	1.028	.419	.080	4
5	3.38	3.25	14.41	1.37	1.31	5.84	.0347	.0690	.502	.933	.0358	3.3	1.017	.398	.080	5
6	3.13	2.84	12.92	1.23	1.11	5.06	.0436	.0690	.632	.917	.0448	2.7	1.027	.382	.080	6
7	23.20	24.52	10.42	******	******	******	.0055	.0690	.080	.984	.0078	41.1	1.008	*****	.067	7
8	2.34	7.39	7.14	1.04	3.28	3.16	.0427	.0690	.618	.917	.0449	5.3	1.047	.423	.080	8
9	3.62	5.70	7.27	1.68	2.65	3.38	.0369	.0690	.535	.931	.0367	-.5	1.029	.451	.080	9
10	5.76	12.42	6.75	3.04	6.56	3.56	.0276	.0690	.399	.948	.0272	-1.2	1.050	.503	.080	10
11	12.12	17.70	9.40	9.21	13.45	7.14	.0197	.0690	.285	.961	.0202	2.6	1.043	.728	.080	11
12	15.73	45.89	9.27	73.00	212.93	43.02	.0120	.0690	.173	.974	.0128	6.6	1.042	4.452	.080	12
13	23.20	24.52	10.42	******	******	******	.0055	.0690	.080	.984	.0078	41.1	1.008	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = 3.215 GRAM/BHP-HR
BSCO ------- = 5.438 GRAM/BHP-HR
BSNOX ------ = 5.361 GRAM/BHP-HR
BSHC + BSNOX = 8.577 GRAM/BHP-HR
CORR. BSFC - = .495 LBS/BHP-HR

TABLE A-3. COMPUTER PRINTOUT OF 13-MODE EMISSIONS TEST ON DEUTZ F3L 912W ON EPA CERTIFICATION FUEL (EM-565-F)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: DEUTZ MODEL F3L912SW S/N 6498515
TEST- FUEL: EM-565-F PROJECT: 05-6800-175 DATE: 9/13/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 673.	0.	.0	.012	2.18	48.	.935	40.	129.	1.70	140.	1.	5.	8.	1
2	2	INTER / 1600.	3.	.8	.050	5.33	49.	.933	76.	191.	1.95	105.	5.	27.	22.	2
3	25	INTER / 1600.	28.	8.4	.090	5.25	40.	.914	65.	121.	3.64	290.	5.	16.	59.	3
4	50	INTER / 1600.	58.	17.6	.132	5.21	42.	.928	58.	87.	5.53	445.	4.	11.	88.	4
5	75	INTER / 1600.	85.	26.0	.180	5.10	44.	.940	56.	91.	7.85	530.	4.	11.	103.	5
6	100	INTER / 1600.	114.	34.8	.252	4.98	44.	.952	58.	293.	11.45	475.	4.	35.	89.	6
7		IDLE / 680.	0.	.0	.013	2.10	49.	.931	42.	112.	1.61	130.	1.	5.	9.	7
8	100	RATED / 2650.	87.	43.7	.350	7.77	46.	.950	60.	209.	10.48	520.	6.	38.	148.	8
9	75	RATED / 2650.	64.	32.5	.253	7.55	42.	.934	98.	182.	6.59	380.	11.	38.	122.	9
10	50	RATED / 2650.	46.	23.2	.208	7.75	46.	.939	102.	200.	5.53	320.	11.	41.	101.	10
11	25	RATED / 2650.	25.	12.6	.150	7.74	51.	.946	96.	251.	4.16	220.	10.	49.	67.	11
12	2	RATED / 2650.	3.	1.3	.105	7.78	51.	.944	154.	406.	2.80	135.	16.	82.	42.	12
13		IDLE / 650.	0.	.0	.013	2.06	44.	.918	64.	341.	1.65	130.	1.	15.	8.	13

MODE	CALCULATED GRAMS/LB-FUEL HC	GRAMS/LB-FUEL CO	GRAMS/LB-FUEL NOX	GRAMS/BHP-HR HC	GRAMS/BHP-HR CO	GRAMS/BHP-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR LB/HP-HR	MODAL WEIGHT FACTOR	MODE
1	1.08	6.90	11.43	******	******	******	.0054	.0690	.078	.981	.0081	50.6	.988	*****	.067	1
2	1.78	8.88	7.43	6.67	33.28	27.86	.0094	.0690	.137	.980	.0094	-.9	1.004	3.734	.080	2
3	.83	3.04	10.87	.54	1.95	6.98	.0172	.0690	.250	.966	.0172	-.3	1.004	.640	.080	3
4	.50	1.44	11.16	.22	.65	5.01	.0254	.0690	.368	.951	.0258	1.7	1.002	.448	.080	4
5	.35	1.06	9.50	.14	.44	3.94	.0355	.0690	.515	.932	.0363	2.0	1.004	.414	.080	5
6	.25	2.34	5.90	.11	1.02	2.56	.0509	.0690	.737	.905	.0521	2.5	1.003	.433	.080	6
7	1.19	6.33	11.17	******	******	******	.0064	.0690	.093	.983	.0077	20.2	.991	*****	.067	7
8	.28	1.83	7.05	.14	.88	3.39	.0453	.0690	.657	.912	.0479	5.7	1.017	.472	.080	8
9	.71	2.53	8.04	.33	1.18	3.76	.0337	.0690	.489	.942	.0307	-9.0	1.016	.461	.080	9
10	.88	3.30	8.10	.47	1.78	4.37	.0271	.0690	.392	.951	.0259	-4.3	1.017	.530	.080	10
11	1.08	5.50	7.44	.77	3.93	5.32	.0195	.0690	.283	.961	.0197	.8	1.017	.703	.080	11
12	2.51	13.06	6.69	11.95	62.08	31.79	.0136	.0690	.197	.973	.0135	-.9	1.018	4.672	.080	12
13	1.75	18.53	10.58	******	******	******	.0065	.0690	.095	.983	.0080	22.8	.991	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = .385 GRAM/BHP-HR
BSCO ------- = 1.851 GRAM/BHP-HR
BSNOX ------ = 4.295 GRAM/BHP-HR
BSHC + BSNOX = 4.679 GRAM/BHP-HR
CORR. BSFC - = .532 LBS/BHP-HR

TABLE A-2. COMPUTER PRINTOUT OF 13-MODE EMISSIONS TEST ON DEUTZ F3L 912W ON MIL-F-46162B(ME) (AL-12287-F)

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: DEUTZ MODEL F3L912SW S/N 6498515
TEST-1 FUEL: AL-12287-F PROJECT: 05-6800-175 DATE: 7/19/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 600.	0.	.0	.013	2.12	73.	1.024	20.	54.	1.56	145.	0.	3.	11.	1
2	2	INTER / 1600.	3.	.8	.037	5.29	73.	1.024	51.	125.	2.10	125.	2.	12.	20.	2
3	25	INTER / 1600.	26.	8.0	.083	5.25	68.	1.002	43.	87.	3.45	285.	3.	12.	62.	3
4	50	INTER / 1600.	54.	16.4	.125	5.23	73.	1.014	52.	75.	5.08	405.	4.	10.	91.	4
5	75	INTER / 1600.	80.	24.4	.167	5.11	74.	1.009	44.	71.	7.30	490.	3.	9.	101.	5
6	100	INTER / 1600.	108.	32.8	.250	4.91	73.	.992	51.	169.	10.86	500.	4.	21.	102.	6
7		IDLE / 600.	0.	.0	.012	1.97	68.	1.00	34.	50.	1.56	155.	1.	2.	10.	7
8	100	RATED / 2650.	87.	43.7	.350	7.57	68.	.987	58.	186.	10.25	495.	6.	35.	150.	8
9	75	RATED / 2650.	66.	33.1	.267	7.65	73.	1.003	80.	155.	7.67	435.	8.	30.	136.	9
10	50	RATED / 2650.	43.	21.9	.198	7.69	78.	1.024	82.	169.	5.53	320.	8.	33.	105.	10
11	25	RATED / 2650.	21.	10.6	.143	7.76	73.	1.016	91.	237.	3.83	210.	10.	48.	71.	11
12	2	RATED / 2650.	1.	.7	.093	7.76	73.	1.020	155.	336.	2.58	110.	15.	66.	36.	12
13		IDLE / 600.	0.	.0	.013	1.97	68.	1.002	41.	87.	1.56	135.	1.	4.	10.	13

MODE	CALCULATED GRAMS/LB-FUEL HC	GRAMS/LB-FUEL CO	GRAMS/LB-FUEL NOX	GRAMS/BHP-HR HC	GRAMS/BHP-HR CO	GRAMS/BHP-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR LB/HP-HR	MODAL WEIGHT FACTOR	MODE
1	.59	3.16	14.21	******	******	******	.0064	.0690	.092	.982	.0074	16.8	.983	*****	.067	1
2	1.12	5.42	9.06	3.08	14.91	24.92	.0070	.0690	.102	.977	.0100	42.9	.997	2.757	.080	2
3	.58	2.31	12.36	.36	1.44	7.72	.0160	.0690	.232	.967	.0163	1.5	.997	.627	.080	3
4	.49	1.35	12.09	.22	.62	5.53	.0242	.0690	.350	.953	.0238	-1.6	.996	.459	.080	4
5	.29	.89	10.14	.12	.37	4.15	.0330	.0690	.478	.935	.0338	2.5	.996	.411	.080	5
6	.23	1.43	6.83	.11	.65	3.12	.0514	.0690	.745	.908	.0495	-3.7	.995	.460	.080	6
7	1.00	2.93	14.91	******	******	******	.0060	.0690	.087	.982	.0074	24.5	.984	*****	.067	7
8	.28	1.66	7.13	.13	.80	3.42	.0467	.0690	.676	.913	.0469	.4	1.012	.475	.080	8
9	.51	1.85	8.50	.24	.89	4.11	.0352	.0690	.511	.932	.0355	.8	1.012	.477	.080	9
10	.71	2.79	8.84	.38	1.52	4.81	.0261	.0690	.378	.949	.0259	-.8	1.013	.537	.080	10
11	1.11	5.64	8.28	.90	4.57	6.71	.0187	.0690	.270	.963	.0181	-2.9	1.014	.800	.080	11
12	2.75	11.74	6.40	23.21	99.22	54.09	.0122	.0690	.176	.974	.0124	2.1	1.015	8.329	.080	12
13	1.20	5.08	12.89	******	******	******	.0068	.0690	.099	.983	.0075	8.9	.985	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = .335 GRAM/BHP-HR
BSCO ------- = 1.472 GRAM/BHP-HR
BSNOX ------ = 4.684 GRAM/BHP-HR
BSHC + BSNOX = 5.019 GRAM/BHP-HR
CORR. BSFC - = .542 LBS/BHP-HR

TABLE A-1. COMPUTER PRINTOUT OF 13-MODE EMISSIONS TEST ON DEUTZ F3L 912W ON MIL-F-46162A(MR), AL-7225-F

13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE:DEUTZ MODEL F3L912SW S/N 6498515 13 MODE
TEST-1 FUEL:EM-544-F PROJECT:05-6800-175 DATE:02/09/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS LB-FT	POWER OBS BHP	FUEL FLOW LB/MIN	AIR FLOW LB/MIN	INTAKE HUMID GR/LB	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 600.	0.	.0	.023	2.80	56.	.927	90.	129.	1.65	99.	3.	10.	12.	1
2	2	INTER / 1600.	3.	.8	.052	5.23	49.	.922	65.	125.	2.20	114.	4.	16.	22.	2
3	25	INTER / 1600.	28.	8.4	.100	5.22	63.	.983	45.	95.	3.90	293.	3.	13.	66.	3
4	50	INTER / 1600.	56.	17.2	.130	5.04	53.	.935	50.	54.	5.38	387.	3.	7.	79.	4
5	75	INTER / 1600.	84.	25.6	.178	5.05	58.	.964	50.	82.	7.95	585.	3.	10.	114.	5
6	100	INTER / 1600.	112.	34.0	.230	4.99	63.	.980	72.	151.	10.25	402.	5.	19.	79.	6
7		IDLE / 600.	0.	.0	.023	2.80	56.	.927	90.	129.	1.65	99.	3.	10.	12.	7
8	100	RATED / 2650.	83.	41.7	.282	7.59	60.	.965	106.	209.	8.24	437.	11.	39.	129.	8
9	75	RATED / 2650.	62.	31.1	.250	7.82	56.	.958	113.	177.	7.21	470.	11.	34.	140.	9
10	50	RATED / 2650.	42.	21.2	.193	7.62	47.	.921	110.	214.	5.69	308.	11.	40.	86.	10
11	25	RATED / 2650.	21.	10.6	.158	7.84	58.	.953	130.	255.	4.30	243.	13.	51.	76.	11
12	2	RATED / 2650.	1.	.7	.100	7.56	45.	.913	160.	356.	3.39	129.	13.	57.	31.	12
13		IDLE / 600.	0.	.0	.023	2.80	56.	.927	90.	129.	1.65	99.	3.	10.	12.	13

MODE	CALCULATED GRAMS/LB-FUEL HC	CALCULATED GRAMS/LB-FUEL CO	CALCULATED GRAMS/LB-FUEL NOX	CALCULATED GRAMS/BHP-HR HC	CALCULATED GRAMS/BHP-HR CO	CALCULATED GRAMS/BHP-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR LB/HP-HR	MODAL WEIGHT FACTOR	MODE
1	2.48	7.09	8.23	******	******	******	.0084	.0690	.122	.983	.0079	-5.6	1.000	*****	.067	1
2	1.36	5.17	7.10	5.26	20.05	27.52	.0099	.0690	.144	.978	.0105	5.5	1.023	3.788	.080	2
3	.54	2.23	11.03	.39	1.59	7.88	.0193	.0690	.280	.963	.0184	-5.1	1.008	.709	.080	3
4	.44	.92	10.06	.20	.42	4.56	.0260	.0690	.376	.951	.0251	-3.3	1.023	.443	.080	4
5	.31	.95	10.61	.13	.40	4.44	.0356	.0690	.516	.931	.0367	3.1	1.014	.412	.080	5
6	.35	1.35	5.75	.14	.55	2.33	.0465	.0690	.674	.913	.0469	.8	1.007	.403	.080	6
7	2.48	7.09	8.23	******	******	******	.0084	.0690	.122	.983	.0079	-5.6	1.000	*****	.067	7
8	.63	2.32	7.64	.25	.94	3.09	.0374	.0690	.543	.928	.0381	1.7	1.041	.389	.080	8
9	.76	2.25	9.32	.36	1.08	4.49	.0322	.0690	.467	.936	.0335	3.9	1.032	.467	.080	9
10	.92	3.44	7.43	.50	1.88	4.06	.0255	.0690	.370	.949	.0266	4.3	1.040	.526	.080	10
11	1.42	5.40	8.00	1.27	4.84	7.17	.0204	.0690	.295	.960	.0203	-.2	1.032	.868	.080	11
12	2.18	9.50	5.13	19.73	86.05	46.47	.0133	.0690	.193	.968	.0162	21.5	1.031	8.783	.080	12
13	2.48	7.09	8.23	******	******	******	.0084	.0690	.122	.983	.0079	-5.6	1.000	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = .454 GRAM/BHP-HR
BSCO ------- = 1.627 GRAM/BHP-HR
BSNOX ------ = 4.445 GRAM/BHP-HR
BSHC + BSNOX = 4.899 GRAM/BHP-HR
CORR. BSFC - = .529 LBS/BHP-HR

APPENDIX A

13-MODE EMISSION TESTS
GROUP I ONLY

Table	Engine Model	Test Fuel
A-1	Deutz F3L 912W	MIL-F-46162A(MR)(AL-7225-F)
A-2	Deutz F3L 912W	MIL-F-46162B(ME)(AL-12287-F)
A-3	Deutz F3L 912W	EPA Certification (EM-565-F)
A-4	Perkins 4.2032	MIL-F-46162A(MR)(AL-7225-F)
A-5	Perkins 4.2032	EPA Certification (EM-565-F)
A-6	Deutz F4L 912W	EPA Certification (EM-565-F)
A-7	Perkins 4.2482	EPA Certification (EM-565-F)

VI. REFERENCES

1. Dietzmann, Harry E., "Clean Burning Diesel Engines." Interim Report AFLRL No. 169, AD A145515, U.S. Army Belvoir R&D Center, Contract No. DAAK70-82-C-0001, August 1983.

2. Code of Federal Regulations, Title 40, Part 86, Subpart D, "Emission Regulations for New Gasoline-Fueled and Diesel Heavy-Duty Engines; Gaseous Exhaust Test Procedures," pp 428-460, 1 July 1982.

3. Smith, L.R., Parness, M.A., Fanick, E.R., Dietzmann, H.E., "Analytical Procedures for Characterizing Unregulated Emissions From Vehicles Using Middle-Distillate Fuels," EPA 600/2-80-068, April 1980.

4. Code of Federal Regulations, Title 40, Part 86, Subpart B, "Emission Regulations for 1977 and Later Model Year New Light-Duty Vehicles and New Light-Duty Trucks; Test Procedures," (particulate tunnel and sampling system) pp 402-465, 1 July 1983.

5. Branstetter, R., Buraham, R., and Dietzmann H., "Relationship of Underground Diesel Engine Maintenance to Emissions," Final Report on Bureau of Mines Contract H0202009, December 1983.

- At rated speed and load, an increase in intake air restriction resulted in an increase in particulate and CO.

- No change in emissions was observed with an increased exhaust restriction.

- Advancing the timing from 17°BTDC to 25°BTDC increased HC, CO, NO_x and particulate emissions.

- In general, virtually all induced faults increased the aldehyde levels, particularly by retarding the injection timing to 13°BTDC.

- Induced faults did not affect sulfur dioxide, sulfate, phenols, or organic sulfides.

Results of this study have provided baseline emissions data to allow assessment of the potential problems when operating diesel engines in areas with limited ventilation.

- Of the organic sulfides detected with the Perkins 4.2032 and 4.2482, carbonyl sulfide was the most predominant.

- No carbonyl sulfide or other organic sulfide was detected in any of the Deutz F3L 912W or Deutz F4L 912W exhaust with any of the fuels.

- DOAS odor values were generally within the range of typically reported values; except the Perkins 4.2032 produced noticeably higher TIA with EM-565-F than other engine-fuel combinations.

Additional unregulated emissions were included in the Group IV analysis; namely, nitropyrenes, PNA compounds, hydrogen sulfide, and selected individual hydrocarbons. A summary of trends and observations for Group IV compounds is presented below:

- None of the unregulated emissions in raw exhaust exceeded the OSHA TLV.

- 1-nitropyrene was the most predominant nitroaromatic compound detected. Brake specific 1-nitropyrene emission rates (µg/hr) were highest at low loads.

- Organic extractables from diesel particulate were highest at idle and low load conditions.

- Phenanthrene and pyrene were the most prevalent PNAs detected.

Engine operation under various malfunctions was determined with selected induced faults. These faults were evaluated on a Deutz F3L 912W, and the results are presented below:

- Sulfate mass emissions (g/hr) were highest at the high load conditions.

- Brake specific sulfate emission rates (g/hp-hr) were highest at low load conditions for all engine-fuel combinations.

- Brake specific particulate rates are highest under low load conditions.

Aldehydes, organic sulfides, phenols, and DOAS odor were included in Group III analyses. General trends and observations are summarized below:

- Formaldehyde was the predominant aldehyde detected, generally accounting for 30-50 percent of the total detected.

- Brake specific formaldehyde emission rates (mg/hp-hr) were highest under low load conditions.

- Formaldehyde emission rates were higher with the high sulfur fuel (AL-12287-F) than the other two fuels.

- Formaldehyde emission rates (mg/hp-hr and mg/hr) were significantly higher on the two Perkins engines than the Deutz engines.

- No phenols were detected with any of the four engines with EM-565-F. Some phenols were detected in exhaust from the Deutz F3L 912W and Perkins 4.2032.

- In general, organic sulfide emission rates did not appear dependent on fuel sulfur level.

V. SUMMARY

This section summarizes emission results from engine and fuel combinations tested in this program. Data for Group I emissions provided several general trends and observations:

- BSCO, $BSNO_x$, and BSHC 13-mode emissions were lowest with the Deutz F3L 912W and Deutz F4L 912W. The highest brake specific HC and CO emissions were observed with the Perkins 4.2032, the Perkins 4.2482 produced the greatest $BSNO_x$ (See Figure 8).

- All engines produced higher BSHC, BSCO and $BSNO_x$ at low load conditions, regardless of speed.

- BSCO and BSHC were lower from the Deutz F3L 912W operating on a MIL-F-46162B(ME) compared to the EPA certification fuel, BSHC was higher and BSCO was lower with MIL-F-46162A(MR) than the EPA certification fuel. $BSNO_x$ emissions were essentially unaffected by fuel type.

Results of Group II emissions for particulate, sulfur dioxide, and sulfate also produced some general trends, and are summarized below:

- At constant speed, sulfur dioxide mass emission rates (g/hr) increase with an increase in load, due primarily to the increase in fuel rate.

- Mass sulfur dioxide emission rates (g/hr) were higher with the high sulfur containing fuel (Al-12287-F) for the Deutz F3L 912W than the MIL-F-46162B(MR) or EPA certification fuel.

- Generally, less than 5-percent of the fuel sulfur is converted to sulfate.

TABLE 31. TREND VALIDATION OF DEUTZ F3L 912W
WITH MIL-F-46162B(ME), AL-12287-F

			Measured Concentration				Mass Emission Rate, g/hr			Brake Specific Emission Rate, g/hp-hr			Fuel Specific Emission Rate, g/lb fuel		
Load, %	Speed, rpm	Run	HC, ppmC	CO, ppm	CO_2, %	NO_x, ppm	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
2	1600	1	51	125	2.10	125	2	12	20	6.16	29.82	49.84	1.12	5.42	9.06
		2	75	147	1.85	108	6	22	25	13.89	54.09	61.59	1.85	7.21	8.21
		3	62	151	1.90	105	4	21	22	10.82	52.34	55.12	1.49	7.22	7.60
		Avg	63	141	1.95	113	4	18	22	10.29	45.42	55.52	1.49	6.62	8.29
25	1600	1	43	87	3.45	285	3	12	62	0.36	1.44	7.72	0.58	2.31	12.36
		2	40	79	3.33	285	3	11	60	0.34	1.32	7.14	0.56	2.17	11.76
		3	46	104	3.52	275	3	14	54	0.36	1.61	6.41	0.61	2.78	10.77
		Avg	43	90	3.43	282	3	12	59	0.35	1.46	7.09	0.58	2.42	11.63
2	2650	1	155	336	2.58	110	15	66	36	23.21	99.22	54.09	2.75	11.74	6.40
		2	105	293	2.63	129	11	60	41	16.58	91.30	61.32	1.83	10.08	6.77
		3	109	307	2.80	120	11	62	37	16.73	92.87	55.34	1.79	9.92	5.91
		Avg	123	312	2.67	120	12	63	38	18.84	94.46	56.92	2.12	10.58	6.36
50	2650	1	82	169	5.53	320	8	33	105	0.38	1.52	4.81	0.71	2.79	8.84
		2	69	160	5.53	310	7	32	95	0.34	1.51	4.48	0.59	2.65	7.85
		3	78	151	5.53	320	8	30	97	0.34	1.51	4.48	0.59	2.65	7.85
		Avg	76	160	5.53	317	8	32	99	0.37	1.48	4.63	0.66	2.65	8.27
100	2650	1	58	186	10.25	495	6	35	150	0.13	0.80	3.42	0.28	1.66	7.13
		2	81	173	9.37	490	8	33	143	0.20	0.78	3.37	0.42	1.69	7.33
		3	102	182	9.91	525	10	33	150	0.24	0.79	3.53	0.51	1.68	7.52
		Avg	80	180	9.84	503	8	34	148	0.19	0.79	3.44	0.40	1.68	7.33
Idle	600	1	34	50	1.56	155	1	2	10	--	--	--	1.00	2.93	14.91
		2	26	71	1.56	140	1	3	10	--	--	--	0.76	4.16	12.03
		3	20	54	1.56	145	0	3	11	--	--	--	0.59	3.16	14.21
		Avg	27	58	1.56	147	1	3	10	--	--	--	0.78	3.42	13.72

APPENDIX B

GROUP II AND III EMISSIONS

TABLE B-1. SUMMARY OF PARTICULATE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (g/hr)

		AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
Engine Speed, rpm	Engine Load, %	Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
Idle	2	1.57	1.24	1.37	1.08	5.96	1.77	1.14
Peak Torque	2	6.97	5.24	4.94	4.38	12.88	7.13	6.74
Peak Torque	25	5.05	9.84	6.86	4.99	9.38	6.81	7.82
Rated	2	9.70	21.28	6.58	13.48	30.40	8.44	14.14
Rated	50	9.33	16.70	15.48	11.61	22.34	9.31	10.02
Rated	100	11.81	31.56	22.27	5.10	32.18	13.89	7.00

[a]AL-7225-F conforms to MIL-F-46162A(MR) fuel specifications
[b]AL-12287-F conforms to MIL-F-46162B(ME) fuel specifications
[c]EM-565-F conforms to EPA DF-2 certification fuel specifications

TABLE B-2. SUMMARY OF PARTICULATE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (g/hp-hr)

Engine Speed, rpm	Engine Load, %	AL-7225-F[a] Deutz F3L 912W	AL-7225-F[a] Perkins 4.2032	AL-12287-F[b] Deutz F3L 912W	EM-565-F[c] Deutz F3L 912W	EM-565-F[c] Perkins 4.2032	EM-565-F[c] Perkins 4.2482	EM-565-F[c] Deutz F4L 912W
Idle	2	*	*	*	*	*	*	*
Peak Torque	2	9.68	6.55	6.18	5.47	16.09	6.79	8.98
Peak Torque	25	0.59	1.00	0.82	0.60	1.00	0.51	0.72
Rated	2	11.28	16.37	9.40	19.26	23.37	4.89	12.30
Rated	50	0.44	0.67	0.73	0.53	0.88	0.24	0.34
Rated	100	0.28	0.68	0.52	0.11	0.62	0.18	0.12

* denotes no horsepower at idle
[a]AL-7225-F conforms to MIL-F-46162A(MR) fuel specifications
[b]AL-12287-F conforms to MIL-F-46162B(ME) fuel specifications
[c]EM-565-F conforms to EPA DF-2 certification fuel specifications

TABLE B-3. SUMMARY OF SULFUR DIOXIDE EMISSION RATES FROM FOUR ENGINES OPERATING ON SEVERAL FUELS (g/hr)

		AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
Engine Speed, rpm	Engine Load, %	Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
Idle	2	2.30	0.73	9.37		4.56	5.24	5.06
Intermediate	2	5.08	4.20	--	--	--	--	--
Peak Torque	2	8.59	8.79	29.09	13.00	13.95	13.51	14.84
Rated	2	16.48	15.21	62.04	22.45	27.00	25.30	40.65
Idle	25	5.18	1.09	--	--	--	--	--
Intermediate	25	12.94	6.45	--	--	--	--	--
Peak Torque	25	15.93	16.88	51.37	18.44	25.35	23.16	25.69
Rated	25	28.79	17.98	--	--	--	--	--
Intermediate	50	14.92	13.35	--	--	--	--	--
Peak Torque	50	23.27	24.90	--	--	--	--	--
Rated	50	23.04	39.02	124.56		57.17	66.90	62.83
Intermediate	100	32.19	34.11	--	--	--	--	--
Peak Torque	100	36.14	41.94	--	--	--	--	--
Rated	100	51.61	40.12	222.79		114.52	133.09	109.00

[a]AL-7225-F conforms to MIL-F-46162A(MR)
[b]AL-12287-F conforms to MIL-F-46162B(ME)
[c]EM-565-F conforms to EPA DF-2 Certification Fuel Specifications

TABLE B-4. SUMMARY OF SULFUR DIOXIDE EMISSION RATES FROM FOUR ENGINES OPERATING ON SEVERAL FUELS (g/hp-hr)

		AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
Engine Speed, rpm	Engine Load, %	Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
Idle	2	11.50	7.30	*	*	*	*	*
Intermediate	2	8.47	8.40	--	--	--	--	--
Peak Torque	2	10.74	10.99	72.73	16.25	17.44	12.29	18.55
Rated	2	23.54	11.70	88.63	32.07	20.77	14.88	33.87
Idle	25	1.99	10.90	--	--	--	--	--
Intermediate	25	2.12	1.02	--	--	--	--	--
Peak Torque	25	1.90	1.72	6.12	2.20	2.70	1.74	2.36
Rated	25	2.72	1.44	--	--	--	--	--
Intermediate	50	1.29	1.03	--	--	--	--	--
Peak Torque	50	1.35	1.28	--	--	--	--	--
Rated	50	1.09	1.56	5.88		2.23	1.79	2.18
Intermediate	100	1.39	1.40	--	--	--	--	--
Peak Torque	100	1.06	1.14	--	--	--	--	--
Rated	100	1.24	0.87	5.25		2.23	1.78	1.95

* denotes no horsepower at idle
[a]AL-7225-F conforms to MIL-F-46162A(MR)
[b]AL-12287-F conforms to MIL-F-46162B(ME)
[c]EM-565-F conforms to EPA DF-2 Certification Fuel Specifications

TABLE B-5. SUMMARY OF SULFATE EMISSION RATES FROM FOUR ENGINES OPERATING ON SEVERAL FUELS (g/hr)

		AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
Engine Speed, rpm	Engine Load, %	Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
Idle	2	0.278	0.115	0.267	0.118	0.186	0.178	0.182
Intermediate	2	0.177	0.256	--	--	--	--	--
Peak Torque	2	0.318	0.241	0.563	0.261	0.403	0.309	0.337
Rated	2	0.404	0.709	0.821	0.530	0.964	0.478	0.335
Idle	25	1.061	0.132	--	--	--	--	--
Intermediate	25	0.252	0.247	--	--	--	--	--
Peak Torque	25	0.452	0.455	1.023	0.337	0.380	0.532	0.253
Rated	25	1.021	0.760	--	--	--	--	--
Intermediate	50	0.270	0.324	--	--	--	--	--
Peak Torque	50	0.501	0.639	--	--	--	--	--
Rated	50	0.784	0.888	3.091	0.983	1.305	1.094	0.916
Intermediate	100	0.401	0.418	--	--	--	--	--
Peak Torque	100	0.693	0.678	--	--	--	--	--
Rated	100	1.021	1.422	4.018	0.572	1.677	1.147	0.471

[a]AL-7225-F conforms to MIL-F-46162A(MR)
[b]AL-12287-F conforms to MIL-F-46162B(ME)
[c]EM-565-F conforms to EPA DF-2 Certification Fuel Specifications

TABLE B-6. SUMMARY OF SULFATE EMISSION RATES FROM FOUR ENGINES OPERATING ON SEVERAL FUELS (g/hp-hr)

		AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
Engine Speed, rpm	Engine Load, %	Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
Idle	2	1.390	1.150	*	*	*	*	*
Intermediate	2	0.295	0.512	--	--	--	--	--
Peak Torque	2	0.398	0.301	1.408	0.326	0.504	0.281	0.449
Rated	2	0.577	0.545	1.173	0.757	0.742	0.281	0.291
Idle	25	0.408	1.320	--	--	--	--	--
Intermediate	25	0.041	0.039	--	--	--	--	--
Peak Torque	25	0.054	0.046	0.122	0.040	0.040	0.040	0.023
Rated	25	0.096	0.061	--	--	--	--	--
Intermediate	50	0.023	0.025	--	--	--	--	--
Peak Torque	50	0.029	0.033	--	--	--	--	--
Rated	50	0.037	0.036	0.146	0.045	0.051	0.029	0.032
Intermediate	100	0.017	0.017	--	--	--	--	--
Peak Torque	100	0.020	0.018	--	--	--	--	--
Rated	100	0.024	0.031	0.095	0.013	0.033	0.016	0.008

* denotes no horsepower at idle
[a]AL-7225-F conforms tc MIL-F-46162A(MR)
[b]AL-12287-F conforms to MIL-F-46162B(ME)
[c]EM-565-F conforms to EPA DF-2 Certification Fuel Specifications

TABLE B-7. SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERL FUELS (mg/hr)

Engine	Engine	Exhaust	Aldehyde and Ketone Emission Rate, mg/hr						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
Speed, rpm	Load, %	Species	AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Formaldehyde	5	1	2	135	140	45	ND
Intermediate	2	Formaldehyde	7	--	--	310	--	--	--
Peak Torque	2	Formaldehyde	14	24	16	470	558	478	ND
Rated	2	Formaldehyde	93	--	--	739	--	--	--
Intermediate	50	Formaldehyde	15	--	--	8	--	--	--
Peak Torque	50	Formaldehyde	32	--	--	49	--	--	--
Rated	50	Formaldehyde	83	--	--	352	--	--	--
Intermediate	100	Formaldehyde	8	--	--	143	--	--	--
Peak Torque	100	Formaldehyde	20	--	--	426	--	--	--
Rated	100	Formaldehyde	17	20	126	541	2111	60	175
Idle	2	Acetaldehyde	ND	ND	1	33	36	4	ND
Intermediate	2	Acetaldehyde	2	--	--	90	--	--	--
Peak Torque	2	Acetaldehyde	2	3	2	133	99	79	ND
Rated	2	Acetaldehyde	28	--	--	199	--	--	--
Intermediate	50	Acetaldehyde	ND	--	--	63	--	--	--
Peak Torque	50	Acetaldehyde	ND	--	--	13	--	--	--
Rated	50	Acetaldehyde	4	--	--	531	--	--	--
Intermediate	100	Acetaldehyde	ND	--	--	25	--	--	--
Peak Torque	100	Acetaldehyde	ND	--	--	141	--	--	--
Rated	100	Acetaldehyde	ND	ND	31	49	366	13	34
Idle	2	Acrolein	2	ND	1	ND	ND	3	1
Intermediate	2	Acrolein	ND	--	--	ND	--	--	--
Peak Torque	2	Acrolein	3	ND	1	ND	ND	31	ND
Rated	2	Acrolein	50	--	--	23	--	--	--
Intermediate	50	Acrolein	4	--	--	15	--	--	--
Peak Torque	50	Acrolein	13	--	--	ND	--	--	--
Rated	50	Acrolein	22	--	--	ND	--	--	--
Intermediate	100	Acrolein	ND	--	--	ND	--	--	--
Peak Torque	100	Acrolein	ND	--	--	ND	--	--	--
Rated	100	Acrolein	4	ND	12	60	ND	10	81

TABLE B-7 (Cont'd). SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (mg/hr)

Engine Speed, rpm	Engine Load, %	Exhaust Species	Aldehyde and Ketone Emission Rate, mg/hr						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
			AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Propionaldehyde	ND	ND	24	15	33	9	24
Intermediate	2	Propionaldehyde	2	--	--	53	--	--	--
Peak Torque	2	Propionaldehyde	3	2	56	66	11	86	40
Rated	2	Propionaldehyde	26	--	--	106	--	--	--
Intermediate	50	Propionaldehyde	ND	--	--	31	--	--	--
Peak Torque	50	Propionaldehyde	ND	--	--	ND	--	--	--
Rated	50	Propionaldehyde	ND	--	--	240	--	--	--
Intermediate	100	Propionaldehyde	2	--	--	15	--	--	--
Peak Torque	100	Propionaldehyde	3	--	--	50	--	--	--
Rated	100	Propionaldehyde	4	ND	36	25	124	153	15
Idle	2	Acetone	ND	ND	ND	ND	ND	36	ND
Intermediate	2	Acetone	ND	--	--	ND	--	--	--
Peak Torque	2	Acetone	ND	ND	ND	ND	ND	ND	ND
Rated	2	Acetone	ND	--	--	ND	--	--	--
Intermediate	50	Acetone	ND	--	--	ND	--	--	--
Peak Torque	50	Acetone	9	--	--	ND	--	--	--
Rated	50	Acetone	21	--	--	ND	--	--	--
Intermediate	100	Acetone	ND	--	--	ND	--	--	--
Peak Torque	100	Acetone	ND	--	--	ND	--	--	--
Rated	100	Acetone	ND	ND	ND	ND	ND	13	ND
Idle	2	Crotonaldehyde	ND	2	1	ND	5	1	1
Intermediate	2	Crotonaldehyde	4	--	--	ND	--	--	--
Peak Torque	2	Crotonaldehyde	7	ND	3	ND	32	18	1
Rated	2	Crotonaldehyde	33	--	--	ND	--	--	--
Intermediate	50	Crotonaldehyde	5	--	--	15	--	--	--
Peak Torque	50	Crotonaldehyde	5	--	--	ND	--	--	--
Rated	50	Crotonaldehyde	16	--	--	28	--	--	--
Intermediate	100	Crotonaldehyde	7	--	--	ND	--	--	--
Peak Torque	100	Crotonaldehyde	21	--	--	ND	--	--	--
Rated	100	Crotonaldehyde	5	3	3	42	ND	18	9

TABLE B-7 (Cont'd). SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (mg/hr)

			Aldehyde and Ketone Emission Rate, mg/hr						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
Engine Speed, rpm	Engine Load, %	Exhaust Species	AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Isobutyraldehyde+MEK	36	2	5	20	20	55	10
Intermediate	2	Isobutyraldehyde+MEK	18	--	--	81	--	--	--
Peak Torque	2	Isobutyraldehyde+MEK	25	8	25	78	86	136	6
Rated	2	Isobutyraldehyde+MEK	260	--	--	96	--	--	--
Intermediate	50	Isobutyraldehyde+MEK	17	--	--	49	--	--	--
Peak Torque	50	Isobutyraldehyde+MEK	25	--	--	44	--	--	--
Rated	50	Isobutyraldehyde+MEK	27	--	--	183	--	--	--
Intermediate	100	Isobutyraldehyde+MEK	15	--	--	24	--	--	--
Peak Torque	100	Isobutyraldehyde+MEK	19	--	--	ND	--	--	--
Rated	100	Isobutyraldehyde+MEK	25	16	35	115	ND	55	57
Idle	2	Benzaldehyde	ND	2	8	ND	ND	15	4
Intermediate	2	Benzaldehyde	3	--	--	49	--	--	--
Peak Torque	2	Benzaldehyde	12	8	22	38	68	253	1
Rated	2	Benzaldehyde	61	--	--	125	--	--	--
Intermediate	50	Benzaldehyde	ND	--	--	28	--	--	--
Peak Torque	50	Benzaldehyde	ND	--	--	23	--	--	--
Rated	50	Benzaldehyde	7	--	--	55	--	--	--
Intermediate	100	Benzaldehyde	6	--	--	16	--	--	--
Peak Torque	100	Benzaldehyde	7	--	--	38	--	--	--
Rated	100	Benzaldehyde	14	16	35	168	189	60	62
Idle	2	Hexanaldehyde	ND	ND	4	ND	27	19	1
Intermediate	2	Hexanaldehyde	ND	--	--	165	--	--	--
Peak Torque	2	Hexanaldehyde	ND	11	7	243	85	69	3
Rated	2	Hexanaldehyde	ND	--	--	312	--	--	--
Intermediate	50	Hexanaldehyde	ND	--	--	18	--	--	--
Peak Torque	50	Hexanaldehyde	5	--	--	27	--	--	--
Rated	50	Hexanaldehyde	ND	--	--	88	--	--	--
Intermediate	100	Hexanaldehyde	ND	--	--	90	--	--	--
Peak Torque	100	Hexanaldehyde	ND	--	--	160	--	--	--
Rated	100	Hexanaldehyde	ND	31	7	36	305	45	6

TABLE B-8. SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERL FUELS (mg/hp-hr)

Engine Speed, rpm	Engine Load, %	Exhaust Species	Aldehyde and Ketone Emission Rate, mg/hp-hr						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
			AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Formaldehyde	25	*	*	1350	*	*	*
Intermediate	2	Formaldehyde	12	--	--	620	--	--	--
Peak Torque	2	Formaldehyde	18	60	20	588	698	435	ND
Rated	2	Formaldehyde	133	--	--	588	--	--	--
Intermediate	50	Formaldehyde	1.3	--	--	0.6	--	--	--
Peak Torque	50	Formaldehyde	1.9	--	--	2.5	--	--	--
Rated	50	Formaldehyde	3.9	--	--	14.1	--	--	--
Intermediate	100	Formaldehyde	0.3	--	--	5.9	--	--	--
Peak Torque	100	Formaldehyde	0.6	--	--	11.6	--	--	--
Rated	100	Formaldehyde	0.4	0.5	2.8	11.7	41.1	0.8	3.2
Idle	2	Acetaldehyde	ND	*	*	330	*	*	*
Intermediate	2	Acetaldehyde	3	--	--	180	--	--	--
Peak Torque	2	Acetaldehyde	3	8	1.5	166	124	72	ND
Rated	2	Acetaldehyde	40	--	--	153	--	--	--
Intermediate	50	Acetaldehyde	ND	--	--	4.8	--	--	--
Peak Torque	50	Acetaldehyde	ND	--	--	0.7	--	--	--
Rated	50	Acetaldehyde	0.2	--	--	21.2	--	--	--
Intermediate	100	Acetaldehyde	ND	--	--	1.0	--	--	--
Peak Torque	100	Acetaldehyde	ND	--	--	3.8	--	--	--
Rated	100	Acetaldehyde	ND	ND	0.7	1.1	7.1	0.2	0.6
Idle	2	Acrolein	10	*	*	ND	*	*	*
Intermediate	2	Acrolein	ND	--	--	ND	--	--	--
Peak Torque	2	Acrolein	4	ND	0.9	ND	ND	28	ND
Rated	2	Acrolein	71	--	--	18	--	--	--
Intermediate	50	Acrolein	0.3	--	--	1.2	--	--	--
Peak Torque	50	Acrolein	0.8	--	--	ND	--	--	--
Rated	50	Acrolein	1.0	--	--	ND	--	--	--
Intermediate	100	Acrolein	ND	--	--	ND	--	--	--
Peak Torque	100	Acrolein	ND	--	--	ND	--	--	--
Rated	100	Acrolein	0.1	ND	0.3	1.3	ND	0.1	1.5

*denotes no horsepower at idle

TABLE B-8 (Cont'd). SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (mg/hp-hr)

			Aldehyde and Ketone Emission Rate, mg/hp-hr						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
Engine Speed, rpm	Engine Load, %	Exhaust Species	AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Propionaldehyde	ND	*	*	150	*	*	*
Intermediate	2	Propionaldehyde	3	--	--	105	--	--	--
Peak Torque	2	Propionaldehyde	4	4	70	83	1.4	78	51
Rated	2	Propionaldehyde	37	--	--	82	--	--	--
Intermediate	50	Propionaldehyde	ND	--	--	2.4	--	--	--
Peak Torque	50	Propionaldehyde	ND	--	--	ND	--	--	--
Rated	50	Propionaldehyde	ND	--	--	9.6	--	--	--
Intermediate	100	Propionaldehyde	0.1	--	--	0.6	--	--	--
Peak Torque	100	Propionaldehyde	0.1	--	--	1.4	--	--	--
Rated	100	Propionaldehyde	0.1	ND	0.8	0.5	2.4	2.0	0.3
Idle	2	Acetone	ND	*	*	ND	*	*	*
Intermediate	2	Acetone	ND	--	--	ND	--	--	--
Peak Torque	2	Acetone	ND	ND	ND	ND	ND	ND	ND
Rated	2	Acetone	ND	--	--	ND	--	--	--
Intermediate	50	Acetone	ND	--	--	ND	--	--	--
Peak Torque	50	Acetone	0.5	--	--	ND	--	--	--
Rated	50	Acetone	1.0	--	--	ND	--	--	--
Intermediate	100	Acetone	ND	--	--	ND	--	--	--
Peak Torque	100	Acetone	ND	--	--	ND	--	--	--
Rated	100	Acetone	ND	ND	ND	ND	ND	0.2	ND
Idle	2	Crotonaldehyde	ND	*	*	ND	*	*	*
Intermediate	2	Crotonaldehyde	7	--	--	ND	--	--	--
Peak Torque	2	Crotonaldehyde	9	ND	3.3	ND	40	16	1.4
Rated	2	Crotonaldehyde	47	--	--	ND	--	--	--
Intermediate	50	Crotonaldehyde	0.4	--	--	1.2	--	--	--
Peak Torque	50	Crotonaldehyde	0.3	--	--	ND	--	--	--
Rated	50	Crotonaldehyde	0.8	--	--	ND	--	--	--
Intermediate	100	Crotonaldehyde	0.3	--	--	ND	--	--	--
Peak Torque	100	Crotonaldehyde	0.6	--	--	ND	--	--	--
Rated	100	Crotonaldehyde	0.1	0.1	0.1	0.9	ND	0.2	0.2

* denotes no horsepower at idle

TABLE B-8 (Cont'd). SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (mg/hp-hr)

			Aldehyde and Ketone Emission Rate, mg/hp-hr						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
Engine Speed, rpm	Engine Load, %	Exhaust Species	AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Isobutyraldehyde+MEK	180	*	*	200	*	*	*
Intermediate	2	Isobutyraldehyde+MEK	30	--	--	162	--	--	--
Peak Torque	2	Isobutyraldehyde+MEK	31	21	32	98	108	124	7.1
Rated	2	Isobutyraldehyde+MEK	372	--	--	74	--	--	--
Intermediate	50	Isobutyraldehyde+MEK	1.4	--	--	3.7	--	--	--
Peak Torque	50	Isobutyraldehyde+MEK	1.4	--	--	2.3	--	--	--
Rated	50	Isobutyraldehyde+MEK	1.3	--	--	7.3	--	--	--
Intermediate	100	Isobutyraldehyde+MEK	0.7	--	--	1.0	--	--	--
Peak Torque	100	Isobutyraldehyde+MEK	0.6	--	--	ND	--	--	--
Rated	100	Isobutyraldehyde+MEK	0.6	0.4	0.8	2.5	ND	0.7	1.0
Idle	2	Benzaldehyde	ND	*	*	ND	*	*	*
Intermediate	2	Benzaldehyde	5	--	--	98	--	--	--
Peak Torque	2	Benzaldehyde	15	21	28	48	85	230	1.8
Rated	2	Benzaldehyde	87	--	--	96	--	--	--
Intermediate	50	Benzaldehyde	ND	--	--	2.2	--	--	--
Peak Torque	50	Benzaldehyde	ND	--	--	1.2	--	--	--
Rated	50	Benzaldehyde	0.3	--	--	2.2	--	--	--
Intermediate	100	Benzaldehyde	0.3	--	--	0.7	--	--	--
Peak Torque	100	Benzaldehyde	0.2	--	--	1.0	--	--	--
Rated	100	Benzaldehyde	0.3	0.4	1.1	3.6	3.7	0.8	1.1
Idle	2	Hexanaldehyde	ND	*	*	ND	*	*	*
Intermediate	2	Hexanaldehyde	ND	--	--	330	--	--	--
Peak Torque	2	Hexanaldehyde	ND	26	8.5	304	73	63	3.5
Rated	2	Hexanaldehyde	ND	--	--	240	--	--	--
Intermediate	50	Hexanaldehyde	ND	--	--	1.4	--	--	--
Peak Torque	50	Hexanaldehyde	0.3	--	--	1.4	--	--	--
Rated	50	Hexanaldehyde	ND	--	--	3.5	--	--	--
Intermediate	100	Hexanaldehyde	ND	--	--	3.7	--	--	--
Peak Torque	100	Hexanaldehyde	ND	--	--	4.3	--	--	--
Rated	100	Hexanaldehyde	ND	0.7	0.2	0.8	5.9	0.6	0.1

* denotes no horsepower at idle

TABLE B-9. SUMMARY OF PHENOL EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS, mg/hr (mg/hp-hr)

Engine Speed, rpm	Engine Load, %	Exhaust Species	Phenol Emission Rate, mg/hr(mg/hp-hr)						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
			AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Phenol	ND	ND	ND	ND	ND	7.43(*)	*
Intermediate	2	Phenol	ND	--	--	ND	--	--	--
Peak Torque	2	Phenol	*	ND	*	38.83(48.54)	ND	36.19(32.90)	*
Rated	2	Phenol	ND	--	--	ND	--	--	--
Intermediate	50	Phenol	ND	--	--	ND	--	--	--
Peak Torque	50	Phenol	ND	--	--	ND	--	--	--
Rated	50	Phenol	ND	--	--	ND	--	--	--
Intermediate	100	Phenol	ND	--	--	ND	--	--	--
Peak Torque	100	Phenol	ND	--	--	20.93(0.57)	--	--	--
Rated	100	Phenol	ND	ND	ND	ND	ND	ND	40.89(0.74)
Idle	2	Salicylaldehyde	ND	ND	ND	ND	ND	17.21(*)	*
Intermediate	2	Salicylaldehyde	ND	--	--	ND	--	--	--
Peak Torque	2	Salicylaldehyde	*	ND	*	9.06(11.33)	ND	6.27(5.70)	*
Rated	2	Salicylaldehyde	ND	--	--	ND	--	--	--
Intermediate	50	Salicylaldehyde	ND	--	--	4.07(0.31)	--	--	--
Peak Torque	50	Salicylaldehyde	ND	--	--	ND	--	--	--
Rated	50	Salicylaldehyde	ND	--	--	ND	--	--	--
Intermediate	100	Salicylaldehyde	ND	--	--	ND	--	--	--
Peak Torque	100	Salicylaldehyde	ND	--	--	ND	--	--	--
Rated	100	Salicylaldehyde	ND	ND	ND	22.80(0.49)	ND	ND	ND
Idle	2	m- & p-cresol	ND	ND	ND	ND	ND	ND	*
Intermediate	2	m- & p-cresol	ND	--	--	ND	--	--	--
Peak Torque	2	m- & p-cresol	*	ND	*	ND	ND	ND	*
Rated	2	m- & p-cresol	ND	--	--	106.19(81.68)	--	--	--
Intermediate	50	m- & p-cresol	ND	--	--	ND	--	--	--
Peak Torque	50	m- & p-cresol	ND	--	--	ND	--	--	--
Rated	50	m- & p-cresol	ND	--	--	49.13(1.97)	--	--	--
Intermediate	100	m- & p-cresol	ND	--	--	ND	--	--	--
Peak Torque	100	m- & p-cresol	ND	--	--	ND	--	--	--
Rated	100	m- & p-cresol	ND	ND	ND	ND	ND	ND	ND

* denotes no horsepower at idle

AD-A152 606   CLEAN-BURNING DIESEL ENGINES(U) SOUTHWEST RESEARCH INST   2/2
SAN ANTONIO TX ARMY FUELS AND LUBRICANTS RESEARCH LAB
H E DIETZMANN DEC 84 AFLRL-178 DAAK70-82-C-0001

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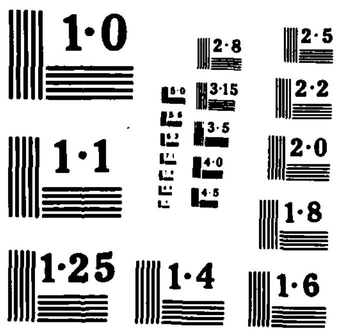
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2·2
3·5
1·1
4·0
2·0
4·5
1·8
1·25
1·4
1·6

TABLE B-9 (Cont'd). SUMMARY OF PHENOL EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS, mg/hr (mg/hp-hr)

			Phenol Emission Rate, mg/hr(mg/hp-hr)						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
Engine Speed, rpm	Engine Load, %	Exhaust Species	AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	Five Phenols	ND	11.71(*)	ND	ND	ND	ND	*
Intermediate	2	Five Phenols	ND	--	--	3.32(6.64)	--	--	--
Peak Torque	2	Five Phenols	*	ND	*	ND	ND	8.15(7.41)	*
Rated	2	Five Phenols	29.04(42.00)	--	--	281.32(216.4)	--	--	--
Intermediate	50	Five Phenols	36.11(3.11)	--	--	15.47(1.19)	--	--	--
Peak Torque	50	Five Phenols	ND	--	--	ND	--	--	--
Rated	50	Five Phenols	261.22(12.32)	--	--	ND	--	--	--
Intermediate	100	Five Phenols	16.90(0.73)	--	--	ND	--	--	--
Peak Torque	100	Five Phenols	30.66(0.90)	--	--	ND	--	--	--
Rated	100	Five Phenols	17.94(0.43)	ND	ND	ND	ND	ND	ND
Idle	2	2-n-propylphenol	ND	ND	ND	ND	ND	3.33(*)	*
Intermediate	2	2-n-propylphenol	ND	--	--	ND	--	--	--
Peak Torque	2	2-n-propylphenol	*	ND	*	ND	ND	13.57(12.33)	*
Rated	2	2-n-propylphenol	ND	--	--	ND	--	--	--
Intermediate	50	2-n-propylphenol	ND	--	--	ND	--	--	--
Peak Torque	50	2-n-propylphenol	ND	--	--	6.51(0.33)	--	--	--
Rated	50	2-n-propylphenol	ND	--	--	ND	--	--	--
Intermediate	100	2-n-propylphenol	ND	--	--	1.58(0.07)	--	--	--
Peak Torque	100	2-n-propylphenol	ND	--	--	2.62(0.07)	--	--	--
Rated	100	2-n-propylphenol	ND	ND	ND	ND	ND	2.56(0.03)	ND
Idle	2	2,3,5-trimethylphenol	ND	ND	ND	3.04(*)	ND	ND	*
Intermediate	2	2,3,5-trimethylphenol	ND	--	--	ND	--	--	--
Peak Torque	2	2,3,5-trimethylphenol	*	ND	*	ND	ND	ND	*
Rated	2	2,3,5-trimethylphenol	13.57(19.39)	--	--	ND	--	--	--
Intermediate	50	2,3,5-trimethylphenol	3.93(0.34)	--	--	ND	--	--	--
Peak Torque	50	2,3,5-trimethylphenol	ND	--	--	ND	--	--	--
Rated	50	2,3,5-trimethylphenol	ND	--	--	ND	--	--	--
Intermediate	100	2,3,5-trimethylphenol	6.14(0.27)	--	--	ND	--	--	--
Peak Torque	100	2,3,5-trimethylphenol	10.61(0.31)	--	--	ND	--	--	--
Rated	100	2,3,5-trimethylphenol	8.97(0.22)	ND	ND	ND	ND	ND	ND

*denotes no horsepower at idle

TABLE B-9 (Cont'd). SUMMARY OF PHENOL EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS, mg/hr (mg/hp-hr)

			Phenol Emission Rate, mg/hr(mg/hp-hr)						
			Deutz F3L 912W			Perkins 4.2032		Perkins 4.2482	Deutz F4L 912W
Engine Speed, rpm	Engine Load, %	Exhaust Species	AL-7225-F	AL-12287-F	EM-565-F	AL-7225-F	EM-565-F	EM-565-F	EM-565-F
Idle	2	2,3,5,6-tetramethylphenol	21.03(105.15)	ND	ND	61.56(*)	ND	ND	*
Intermediate	2	2,3,5,6-tetramethylphenol	299.45(499.08)	--	--	299.70(599.4)	--	--	--
Peak Torque	2	2,3,5,6-tetramethylphenol	*	ND	*	ND	ND	ND	*
Rated	2	2,3,5,6-tetramethylphenol	128.89(184.13)	--	--	ND	--	--	--
Intermediate	50	2,3,5,6-tetramethylphenol	306.94(26.46)	--	--	ND	--	--	--
Peak Torque	50	2,3,5,6-tetramethylphenol	14.02(0.82)	--	--	ND	--	--	--
Rated	50	2,3,5,6-tetramethylphenol	206.50(9.74)	--	--	489.47(25.1)	--	--	--
Intermediate	100	2,3,5,6-tetramethylphenol	ND	--	--	ND	--	--	--
Peak Torque	100	2,3,5,6-tetramethylphenol	195.75(5.76)	--	--	ND	--	--	--
Rated	100	2,3,5,6-tetramethylphenol	ND	ND	ND	53.21(1.15)	ND	ND	ND

*denotes no horsepower at idle

TABLE B-11. SUMMARY OF ORGANIC SULFIDE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (mg/hp-hr)

Organic Sulfide	Engine Speed, rpm	Engine Load, %	Organic Sulfide Emission Rate, mg/hp-hr						
			AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
			Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
COS	Idle	2	ND	9.00	--	--	--	--	--
COS	Intermediate	2	ND	6.82	NR	NR	NR	NR	NR
COS	Peak Torque	2	ND	5.96	ND	ND	19.88	ND	ND
COS	Rated	2	ND	34.68	NR	NR	NR	NR	NR
COS	Intermediate	50	ND	0.04	NR	NR	NR	NR	NR
COS	Peak Torque	50	ND	0.05	NR	NR	NR	NR	NR
COS	Rated	50	ND	0.65	NR	NR	NR	NR	NR
COS	Intermediate	100	ND	0.04	NR	NR	NR	NR	NR
COS	Peak Torque	100	ND	0.04	NR	NR	NR	NR	NR
COS	Rated	100	ND	0.06	ND	ND	0.19	0.06	ND
$(CH_3)_2S$	Idle	2	ND	ND	--	--	--	--	--
$(CH_3)_2S$	Intermediate	2	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Peak Torque	2	ND	ND	ND	ND	ND	3.07	ND
$(CH_3)_2S$	Rated	2	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Intermediate	50	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Peak Torque	50	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Rated	50	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Intermediate	100	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Peak Torque	100	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Rated	100	ND	ND	ND	ND	ND	0.04	ND
$(C_2H_5)_2S$	Idle	2	ND	ND	--	--	--	--	--
$(C_2H_5)_2S$	Intermediate	2	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Peak Torque	2	ND	ND	ND	ND	ND	1.91	ND
$(C_2H_5)_2S$	Rated	2	ND	4.72	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Intermediate	50	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Peak Torque	50	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Rated	50	ND	0.06	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Intermediate	100	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Peak Torque	100	ND	0.01	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Rated	100	ND	0.07	ND	ND	0.12	0.05	ND

[a]AL-7225-F confirms to MIL-F-46162A(MR)
[b]AL-12287-F confirms to MIL-F-46162B(ME)
[c]EM-565-F confirms to EPA DF-2 certification fuel specifications
ND denotes Not Detected; NR denotes Not Run

TABLE B-10. SUMMARY OF ORGANIC SULFIDE EMISSION RATES FROM FOUR DIESEL FORKLIFT ENGINES OPERATING ON SEVERAL FUELS (mg/hr)

			Organic Sulfide Emission Rate, mg/hr						
			AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
Organic Sulfide	Engine Speed, rpm	Engine Load, %	Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
COS	Idle	2	ND	0.90	ND	ND	ND	ND	ND
COS	Intermediate	2	ND	3.41	NR	NR	NR	NR	NR
COS	Peak Torque	2	ND	4.77	ND	ND	15.90	ND	ND
COS	Rated	2	ND	45.08	NR	NR	NR	NR	NR
COS	Intermediate	50	ND	0.58	NR	NR	NR	NR	NR
COS	Peak Torque	50	ND	0.94	NR	NR	NR	NR	NR
COS	Rated	50	ND	16.33	NR	NR	NR	NR	NR
COS	Intermediate	100	ND	1.00	NR	NR	NR	NR	NR
COS	Peak Torque	100	ND	1.32	NR	NR	NR	NR	NR
COS	Rated	100	ND	2.94	ND	ND	9.60	4.57	ND
$(CH_3)_2S$	Idle	2	ND	ND	ND	ND	ND	ND	ND
$(CH_3)_2S$	Intermediate	2	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Peak Torque	2	ND	ND	ND	ND	ND	3.38	ND
$(CH_3)_2S$	Rated	2	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Intermediate	50	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Peak Torque	50	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Rated	50	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Intermediate	100	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Peak Torque	100	ND	ND	NR	NR	NR	NR	NR
$(CH_3)_2S$	Rated	100	ND	ND	ND	ND	ND	2.85	ND
$(C_2H_5)_2S$	Idle	2	ND	ND	ND	ND	ND	ND	ND
$(C_2H_5)_2S$	Intermediate	2	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Peak Torque	2	ND	ND	ND	ND	ND	2.10	ND
$(C_2H_5)_2S$	Rated	2	ND	2.59	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Intermediate	50	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Peak Torque	50	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Rated	50	ND	1.55	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Intermediate	100	ND	ND	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Peak Torque	100	ND	0.43	NR	NR	NR	NR	NR
$(C_2H_5)_2S$	Rated	100	ND	3.42	ND	ND	6.30	3.72	ND

[a]AL-7225-F confirms to MIL-F-46162A(MR)
[b]AL-12287-F confirms to MIL-F-46162B(ME)
[c]EM-565-F confirms to EPA DF-2 certification fuel specifications
ND denotes Not Detected; NR denotes Not Run

TABLE B-12. SUMMARY OF DIESEL ODOR ANALYSIS SYSTEM (DOAS) RESULTS FROM FOUR ENGINES OPERATING ON SEVERAL FUELS

		AL-7225-F[a]		AL-12287-F[b]	EM-565-F[c]			
Engine Speed, rpm	Engine Load, %	Deutz F3L 912W	Perkins 4.2032	Deutz F3L 912W	Deutz F3L 912W	Perkins 4.2032	Perkins 4.2482	Deutz F4L 912W
Idle	2	1.55	2.10	1.58	1.53	--	0.51	1.59
Intermediate	2	1.55	2.17	NR	NR	NR	NR	NR
Peak Torque	2	1.71	2.07	1.95	1.39	2.27	1.66	1.48
Rated	2	1.92	2.08	NR	NR	NR	NR	NR
Intermediate	50	1.77	2.21	NR	NR	NR	NR	NR
Peak Torque	50	1.62	2.28	NR	NR	NR	NR	NR
Rated	50	1.71	2.52	NR	NR	NR	NR	NR
Intermediate	100	1.72	2.17	NR	NR	NR	NR	NR
Peak Torque	100	1.41	2.57	NR	NR	NR	NR	NR
Rated	100	1.38	--	2.14	2.04	2.91	1.87	2.06

[a]AL-7225-F confirms to MIL-F-46162A(MR)
[b]AL-12287-F confirms to MIL-F-46162B(ME)
[c]EM-565-F confirms to *EPA DF-2 certification fuel specifications*

TABLE B-13. ADDITIONAL PNA COMPOUNDS IN ORGANIC EXTRACTABLES TENTATIVELY IDENTIFIED BY GC-MS

Compound	Deutz F3L 912W (AL-12287-F) Idle	Deutz F3L 912W (AL-12287-F) 2% Load 1600 rpm	Deutz F3L 912W (AL-12287-F) 100% Load 2650 rpm	Perkins 4.2032 (EM-565-F) Idle	Perkins 4.2032 (EM-565-F) 2% Load 1500 rpm	Perkins 4.2032 (EM-565-F) 100% Load 2500 rpm	Deutz F4L 912W (EM-565-F) Idle	Deutz F4L 912W (EM-565-F) 2% Load 1500 rpm	Deutz F4L 912W (EM-565-F) 100% Load 2300 rpm
C_2 biphenyl	X	X		X	X	X		X	X
diethyleneglycol						X		X	
butoxyethoxyethanol						X		X	
di-t-butylphenol				X				X	
benzene dicarboxylic acid				X			X	X	
tetramethylbutyl phenol								X	
fluorenone	X	X	X	X	X	X	X	X	X
methylphenanthrenes/ methylanthracenes	X	X	X	X	X	X	X	X	X
C_2 phenanthrenes/ C_2 anthracenes	X	X	X	X	X	X	X	X	X
C_3 phenanthrenes/ C_3 anthracenes	X	X	X	X	X	X	X	X	X
benz(d,e)anthracenone	X	X	X	X	X	X	X	X	X
C_3 naphthalenes	X	X	X	X	X	X	X	X	X
C_4 naphthalenes	X	X	X	X	X	X	X	X	X
naphthopyradione	X	X	X	X	X	X		X	
terphenyl	X	X	X	X	X	X		X	X
tributylphosphate			X						
anthracendione	X	X	X	X	X	X		X	X
methyl fluorene	X	X	X	X	X	X		X	X
methylpyrene	X	X	X	X	X	X		X	X
C_4 phenanthrenes/ C_4 anthracenes		X	X	X	X	X		X	
pentachlorophenol						X			

X - denotes PNA compound tentatively identified

APPENDIX C

INDUCED FAULTS EMISSION RATES

TABLE C-1. SUMMARY OF HC, CO, AND NO_x EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (g/hp-hr)

			HC Emission Rate, g/hp-hr				CO Emission Rate, g/hp-hr				NO_x Emission Rate, g/hp-hr			
Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	--	11.95	0.47	0.14	--	62.08	1.78	0.88	--	31.79	4.37	3.39
3	12.5	17	--	27.09	0.50	0.21	--	132.17	1.68	0.96	--	63.44	4.61	3.41
6	12.5	17	--	29.26	0.54	0.18	--	143.42	1.81	1.01	--	62.84	4.35	3.03
1.5	25	17	--	34.02	0.45	0.15	--	165.53	1.81	1.47	--	59.63	4.05	2.88
1.5	50	17	--	50.53	0.44	0.13	--	207.42	1.67	1.31	--	57.90	3.55	2.81
1.5	12.5	13	--	94.85	0.49	0.15	--	311.25	1.99	0.90	--	46.58	3.61	2.93
1.5	12.5	21	--	15.63	0.55	0.24	--	84.22	1.63	0.96	--	116.64	7.12	4.89
1.5	12.5	25	--	19.23	0.62	0.31	--	95.82	1.78	1.43	--	133.41	8.82	5.69

TABLE C-2. SUMMARY OF HC, CO, AND NO_x EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (g/hr)

Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	HC Emission Rate, g/hr				CO Emission Rate, g/hr				NO_x Emission Rate, g/hr			
			Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	1	16	11	6	5	82	41	38	8	42	101	148
3	12.5	17	2	18	11	9	8	88	38	43	11	42	104	154
6	12.5	17	1	19	12	8	7	95	40	45	11	42	95	134
1.5	25	17	1	23	10	7	6	110	40	65	11	40	89	128
1.5	50	17	7	33	10	5	12	137	36	51	11	38	78	110
1.5	12.5	13	4	63	11	6	9	206	43	37	8	31	79	120
1.5	12.5	21	2	10	12	11	10	56	36	43	17	77	156	220
1.5	12.5	25	1	13	14	14	7	63	39	63	20	88	193	240

TABLE C-3. SUMMARY OF HC, CO, AND NO_x EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (ppm)

			HC Emission Rate, ppmC				CO Emission Rate, ppm				NO_x Emission Rate, ppm			
Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	40	154	102	60	129	406	200	209	140	135	320	520
3	12.5	17	65	172	110	93	147	426	191	232	130	130	330	525
6	12.5	17	55	190	119	83	129	473	209	255	140	130	325	495
1.5	25	17	41	230	101	72	95	569	214	386	125	130	300	480
1.5	50	17	236	392	112	57	218	821	223	327	128	150	300	445
1.5	12.5	13	140	640	106	61	173	1068	223	195	100	100	255	410
1.5	12.5	21	59	105	120	109	186	288	186	237	205	245	500	765
1.5	12.5	25	68	127	134	140	164	322	200	346	305	280	635	875

TABLE C-4. SUMMARY OF PARTICULATE, SULFATE, AND SULFUR DIOXIDE EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (g/hp-hr)

Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	Particulate Emission Rate, g/hp-hr				Sulfate Emission Rate, g/hp-hr				Sulfur Dioxide Emission Rate, g/hp-hr			
			Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	--	19.26	0.53	0.11	--	0.757	0.045	0.013	--	32.07	2.39	2.00
3	12.5	17	--	13.74	0.44	0.17	--	0.453	0.047	0.015	--	38.12	1.99	2.17
6	12.5	17	--	10.31	0.40	0.12	--	0.499	0.056	0.020	--	39.97	2.49	2.05
1.5	25	17	--	12.92	0.40	0.28	--	0.508	0.042	0.018	--	38.45	2.48	2.18
1.5	50	17	--	12.35	0.33	0.30	--	0.647	0.043	0.014	--	43.53	2.73	2.37
1.5	12.5	13	--	29.16	0.36	0.18	--	0.776	0.043	0.029	--	40.62	2.69	2.40
1.5	12.5	21	--	10.74	0.56	0.16	--	0.642	0.047	0.022	--	36.97	2.10	1.47
1.5	12.5	25	--	12.41	0.61	0.33	--	0.693	0.044	0.018	--	4.033	ND	ND

FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED
ENGINE FAULTS (g/hr)

Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	Particulate Emission Rate, g/hr				Sulfate Emission Rate, g/hr				Sulfur Dioxide Emission Rate, g/hr			
			Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	1.08	13.48	11.61	5.10	0.118	0.530	0.983	0.572	3.96	22.45	52.17	88.65
3	12.5	17	0.87	9.07	9.88	7.65	0.140	0.317	1.047	0.690	4.44	26.69	44.74	98.04
6	12.5	17	0.81	8.87	8.64	5.04	0.128	0.349	1.226	0.902	4.48	27.98	54.44	91.19
1.5	25	17	0.81	8.53	8.88	12.55	0.128	0.356	0.919	0.806	4.45	26.91	54.24	96.71
1.5	50	17	2.34	8.15	7.25	11.65	0.177	0.453	0.942	0.532	5.00	30.41	59.77	92.68
1.5	12.5	13	1.42	18.66	7.77	7.58	0.120	0.543	0.936	1.190	4.16	28.43	58.87	98.52
1.5	12.5	21	2.50	7.09	12.34	7.38	0.190	0.450	1.036	1.006	2.51	25.88	46.02	66.12
1.5	12.5	24	0.87	8.19	13.38	14.43	0.174	0.485	0.966	0.800	4.09	28.23	ND	ND

TABLE C-6. SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (mg/hp-hr)

			Formaldehyde Emission Rate, mg/hp-hr				Acetaldehyde Emission Rate, mg/hp-hr				Acrolein Emission Rate, mg/hp-hr			
Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	--	--	--	2.8	--	--	--	0.7	--	--	--	0.3
3	12.5	17	--	599	3.8	1.6	--	19	ND	0.2	--	ND	0.3	1.4
6	12.5	17	--	346	1.7	10.6	--	24	ND	0.6	--	20	0.1	2.0
1.5	25	17	--	501	1.3	9.3	--	27	ND	0.5	--	37	0.1	1.6
1.5	50	17	--	2044	0.4	2.3	--	439	ND	0.1	--	139	0.1	0.8
1.5	12.5	13	--	7273	5.4	5.4	--	1980	1.3	0.2	--	1546	1.2	0.9
1.5	12.5	21	--	21	0.4	1.2	--	ND	ND	ND	--	7	0.1	0.2
1.5	12.5	25	--	106	ND	0.4	--	11	ND	ND	--	23	0.2	ND

			Propionaldehyde Emission Rate, mg/hp-hr				Crotonaldehyde Emission Rate, mg/hp-hr				Isobutyraldehyde Emission Rate, mg/hp-hr			
Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	--	--	--	0.8	--	--	--	0.1	--	--	--	0.8
3	12.5	17	--	229	6.7	0.4	--	ND	0.4	0.2	--	79	4.0	0.4
6	12.5	17	--	326	4.2	0.7	--	43	ND	0.3	--	134	1.4	1.8
1.5	25	17	--	144	3.5	0.5	--	14	0.3	0.3	--	74	2.0	1.6
1.5	50	17	--	474	5.4	0.5	--	114	0.1	0.2	--	261	1.2	0.7
1.5	12.5	13	--	664	2.1	0.8	--	310	0.7	0.4	--	961	1.9	2.2
1.5	12.5	21	--	209	3.6	0.5	--	ND	ND	0.1	--	63	0.9	0.3
1.5	12.5	25	--	126	3.6	0.3	--	ND	ND	ND	--	47	0.5	0.1

			Hexanaldehyde Emission Rate, mg/hp-hr				Benzaldehyde Emission Rate, mg/hp-hr			
Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	--	--	--	0.2	--	--	--	1.1
3	12.5	17	--	6	0.9	ND	--	127	2.2	1.8
6	12.5	17	--	ND	0.7	0.5	--	384	2.6	7.3
1.5	25	17	--	ND	ND	0.4	--	370	1.9	2.3
1.5	50	17	--	ND	0.3	ND	--	1853	1.6	2.6
1.5	12.5	13	--	161	ND	ND	--	3759	5.7	7.0
1.5	12.5	21	--	ND	ND	ND	--	46	0.7	1.2
1.5	12.5	25	--	10	ND	ND	--	50	0.5	0.3

ND denotes not detected, values were less than the MVD (minimum detection value)

TABLE C-7. SUMMARY OF ALDEHYDE AND KETONE EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (mg/hr)

Exhaust B.P., "Hg	Inlet Restric. "H2O	Injection Timing, BTDC	Formaldehyde Emission Rate, mg/hr Idle	Formaldehyde 2650 rpm 2% Load	Formaldehyde 2650 rpm 50% Load	Formaldehyde 2650 rpm 100% Load	Acetaldehyde Emission Rate, mg/hr Idle	Acetaldehyde 2650 rpm 2% Load	Acetaldehyde 2650 rpm 50% Load	Acetaldehyde 2650 rpm 100% Load	Acrolein Emission Rate, mg/hr Idle	Acrolein 2650 rpm 2% Load	Acrolein 2650 rpm 50% Load	Acrolein 2650 rpm 100% Load
1.5	12.5	17	2	--	--	126	1	--	--	31	1	--	--	12
3	12.5	17	24	419	86	71	1	13	ND	8	1	ND	6	63
6	12.5	17	2	242	37	472	ND	17	ND	27	ND	14	1	91
1.5	25	17	7	351	29	412	ND	19	ND	23	1	26	2	71
1.5	50	17	23	1431	8	88	5	307	ND	4	1	97	2	31
1.5	12.5	13	ND	5091	118	223	ND	1386	28	7	ND	1082	26	38
1.5	12.5	21	163	51	8	52	14	ND	ND	ND	ND	5	2	10
1.5	12.5	25	ND	74	ND	18	1	8	ND	ND	1	16	4	ND

Exhaust B.P., "Hg	Inlet Restric. "H2O	Injection Timing, BTDC	Propionaldehyde Emission Rate, mg/hr Idle	Propionaldehyde 2650 rpm 2% Load	Propionaldehyde 2650 rpm 50% Load	Propionaldehyde 2650 rpm 100% Load	Crotonaldehyde Emission Rate, mg/hr Idle	Crotonaldehyde 2650 rpm 2% Load	Crotonaldehyde 2650 rpm 50% Load	Crotonaldehyde 2650 rpm 100% Load	Isobutyraldehyde Emission Rate, mg/hr Idle	Isobutyraldehyde 2650 rpm 2% Load	Isobutyraldehyde 2650 rpm 50% Load	Isobutyraldehyde 2650 rpm 100% Load
1.5	12.5	17	24	--	--	36	1	--	--	3	5	--	--	35
3	12.5	17	27	160	151	17	2	ND	8	7	13	55	91	17
6	12.5	17	15	228	93	33	ND	30	ND	14	9	94	30	79
1.5	25	17	29	101	76	22	1	10	7	13	3	52	43	69
1.5	50	17	20	332	119	19	1	80	2	7	8	183	27	26
1.5	12.5	13	26	465	45	31	1	217	16	16	10	673	41	73
1.5	12.5	21	9	146	78	24	ND	ND	ND	1	2	44	19	15
1.5	12.5	25	18	88	79	13	1	ND	ND	ND	7	33	11	6

Exhaust B.P., "Hg	Inlet Restric. "H2O	Injection Timing, BTDC	Hexanaldehyde Emission Rate, mg/hr Idle	Hexanaldehyde 2650 rpm 2% Load	Hexanaldehyde 2650 rpm 50% Load	Hexanaldehyde 2650 rpm 100% Load	Benzaldehyde Emission Rate, mg/hr Idle	Benzaldehyde 2650 rpm 2% Load	Benzaldehyde 2650 rpm 50% Load	Benzaldehyde 2650 rpm 100% Load
1.5	12.5	17	4	--	--	7	8	--	--	35
3	12.5	17	6	4	21	ND	11	89	49	80
6	12.5	17	3	ND	16	21	5	269	36	322
1.5	25	17	2	ND	ND	0.4	5	259	41	103
1.5	50	17	7	ND	6	ND	13	1297	35	100
1.5	12.5	13	3	113	ND	ND	3	2631	124	288
1.5	12.5	21	ND	ND	ND	ND	1	32	16	56
1.5	12.5	25	3	7	ND	ND	4	32	12	11

ND denotes not detected, values were less than the MDV (minimum detection value)

TABLE C-8. SUMMARY OF ORGANIC SULFUDE EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (mg/hp-hr)

Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, BTDC	COS Emission Rate, mg/hp-hr				$(CH_3)_2S$ Emission Rate, mg/hp-hr				$(C_2H_5)_2S$ Emission Rate, mg/hp-hr[a]			
			Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	ND[b]	--	--	ND	ND	--	--	ND	ND	ND	ND	ND
3	12.5	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	12.5	17	ND	ND	ND	ND	ND	ND	0.05	ND	ND	ND	ND	ND
1.5	25	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1.5	50	17	ND	12.93	ND	ND	ND	4.57	ND	ND	ND	ND	ND	ND
1.5	12.5	13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1.5	12.5	21	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1.5	12.5	25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.04	0.01

[a]No dimethyldisulfide was detected under any induced faults at any engine condition
[b]ND denotes not detected, values were less than the MDV (minimum detection value)

TABLE C-9. SUMMARY OF ORGANIC SULFUDE EMISSION RATES FROM A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS (mg/hp-hr)

Exhaust B.P., "Hg	Inlet Restric. "H_2O	Injection Timing, °BTDC	COS Emission Rate, mg/hr				$(CH_3)_2S$ Emission Rate, mg/hr				$(C_2H_5)_2S$ Emission Rate, mg/hr[a]			
			Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load	Idle	2650 rpm 2% Load	2650 rpm 50% Load	2650 rpm 100% Load
1.5	12.5	17	ND[b]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	12.5	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	12.5	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1.5	25	17	ND	ND	ND	ND	ND	3.20	ND	ND	ND	ND	ND	ND
1.5	50	17	ND	9.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1.5	12.5	13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1.5	12.5	21	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1.5	12.5	25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.86	0.53

[a]No dimethyldisulfide was detected under any induced faults at any engine condition
[b]ND denotes not detected, values were less than the MDV (minimum detection value)

TABLE C-10. SUMMARY OF DIESEL ODOR ANALYSIS SYSTEM (DOAS) RESULTS FOR A DEUTZ F3L 912W OPERATING ON EM-565-F WITH SELECTED INDUCED ENGINE FAULTS

Exhaust B.P., "Hg	Inlet Restriction, "H_2O	Injection Timing, BTDC	DOAS Odor at Engine Test Condition (TIA)			
			Idle	2650 rpm 2% Load	2650 rpm 50%Load	2650 rpm 100% Load
1.5*	12.5*	17*	1.53	--	--	2.04
3	12.5	17	0.90	1.81	1.82	1.91
6	12.5	17	1.49	2.04	1.97	1.96
1.5	25	17	1.48	1.50	1.73	1.70
1.5	50	17	0.68	1.51	1.79	1.87
1.5	12.5	13	1.48	2.61	2.42	2.49
1.5	12.5	21	1.84	1.95	1.27	2.00
1.5	12.5	25	1.54	1.69	1.82	1.23

*Standard condition

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